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SOME FEATURES OF SOUND BEHAVIOR IN RELATION TO THERMAL AND SALI--ETC(U)
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# Some features of sound behavior in relation to thermal and salinity structure in the North Pacific.

Fleet Numerical Weather Facility
Monterey, California

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## 1. Purpose

The purpose of these brief notes is

(1) to facilitate the interpretation of some oceanographic analyses and prediction charts already issued or in preparation by FNWF, in respect to sound behavior;

(2) to describe some short-term fluctuations in thermal structure (e.g., 'afternoon effect') which, because of their short duration, cannot be included in the analyses and predictions; and

(3) to describe the upper sound channel, which is important in increasing surface sound transmission losses but increases considerably the propagation distances of nearly horizontal low-frequency sound at its depth.

## 2. "Sonic layer" depth in relation to mixed layer depth

Because of the nonlinear relation between sound velocity and temperature and because of the interacting effect of pressure (depth) on the sound velocity, the mixed layer depth and sonic layer depth are not identical. The sonic layer depth can, for example, be the same in two locations, even though the temperature change with depth may be rapid in one and slow in another location.

In general the sonic layer depth is somewhat deeper than the mixed layer depth.

The relations between temperature, depth and sound velocity are shown on Figure 1.

It can be noted that:

1°C increase of temperature increases the sound speed 4.6 m $sec^{-1}$,

100 meter depth increase increases the sound velocity 1.8 m $sec^{-1}$, and

1°/oo increase of salinity increases the sound velocity 1.3 m $sec^{-1}$, or

about 0.25°F decrease of temperature within 100 feet of depth would balance the pressure effect.

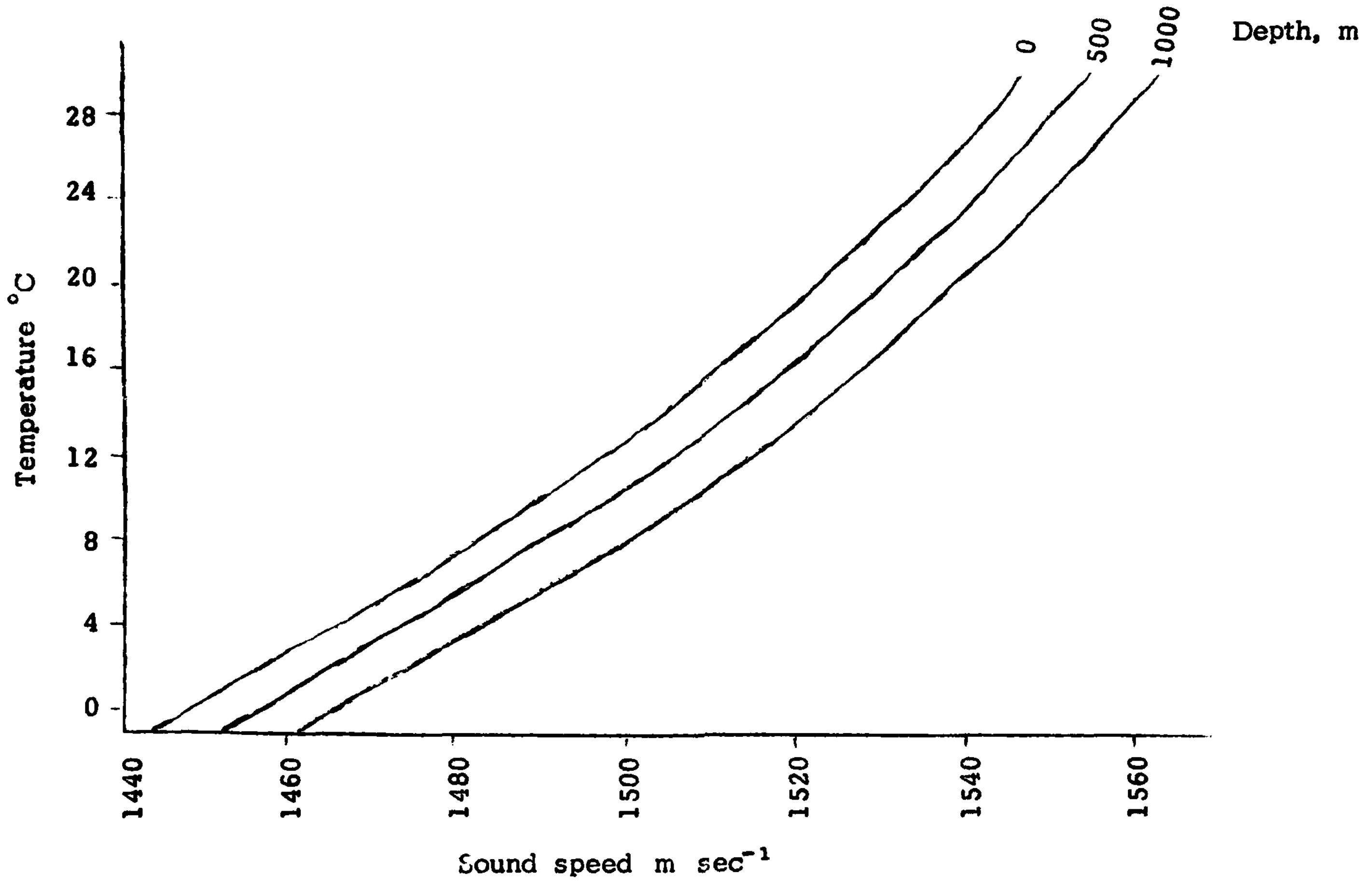


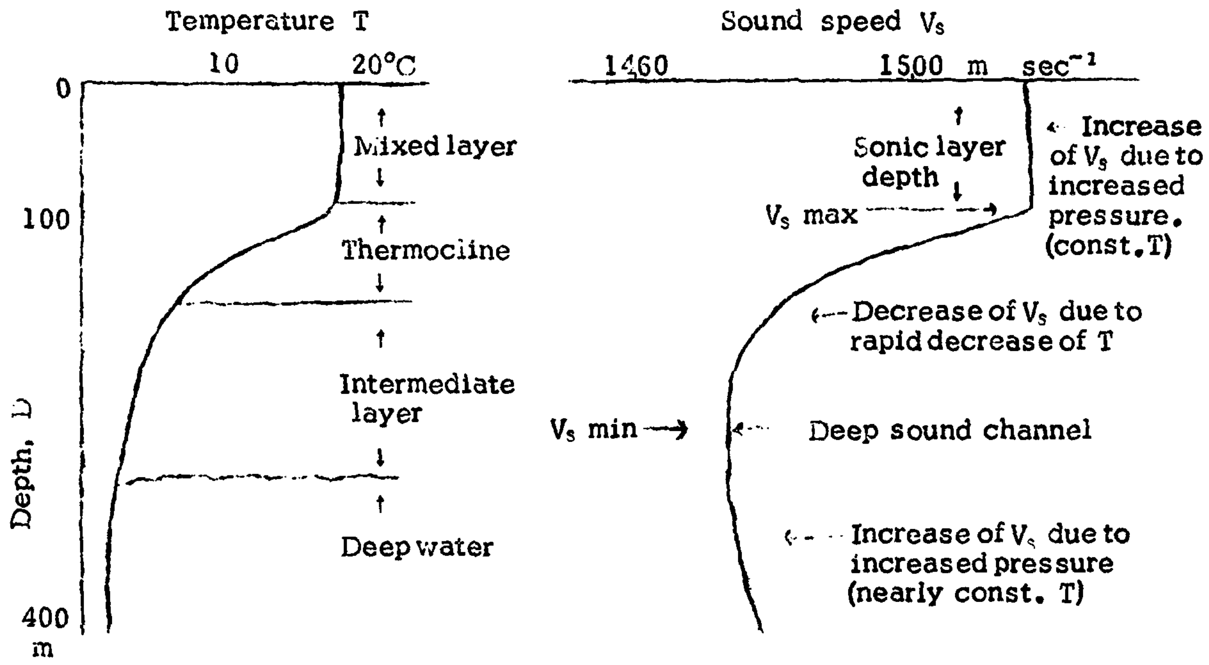
Figure 1. Sound velocity nomogram.

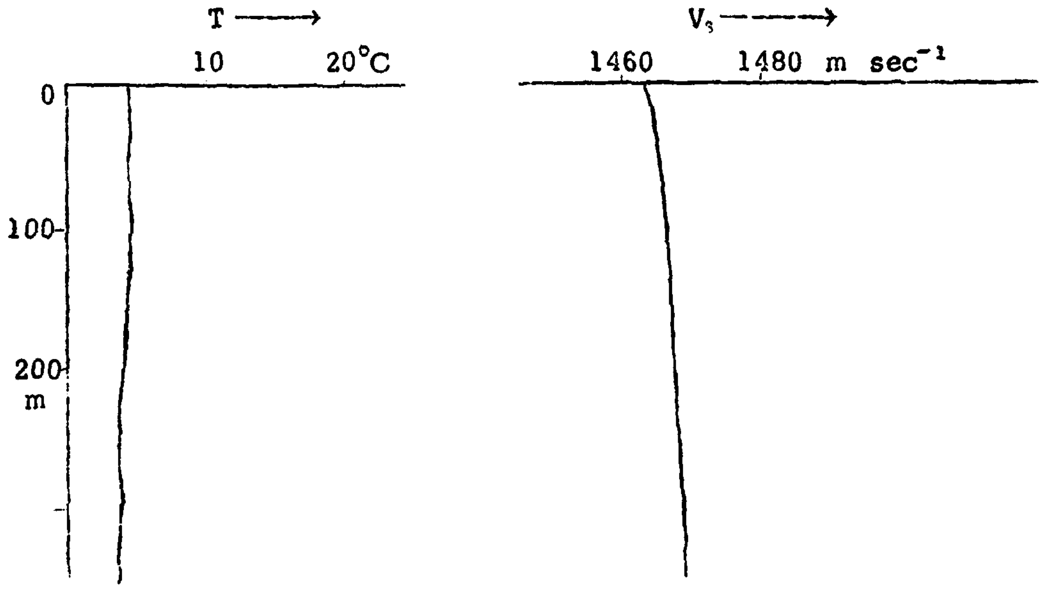
## 3. Types of vertical sound velocity profiles as determined by oceanographic conditions

Sound velocity increases with increasing temperature, pressure (depth) and salinity. The salinity effects are relatively small compared to temperature effects, as the vertical changes in salinity are relatively small in the greatest part of open ocean. In the first five types of vertical sound velocity profiles the salinity effects are therefore neglected.

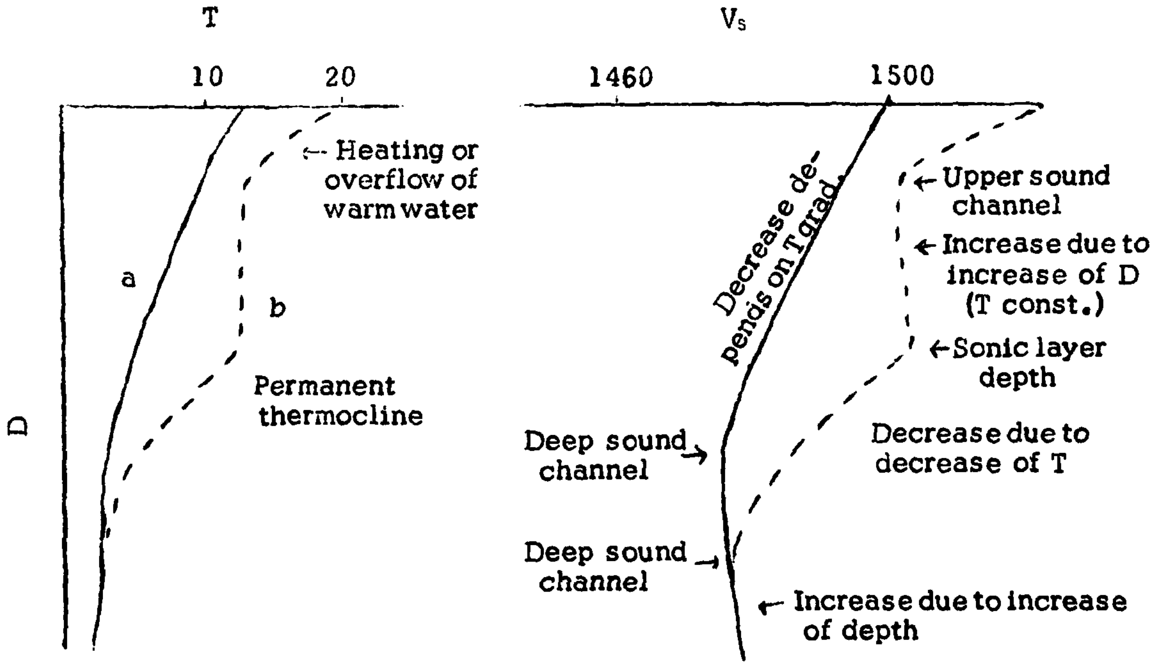
1. Normal model.

a) Temperature profile b) Sound velocity profile





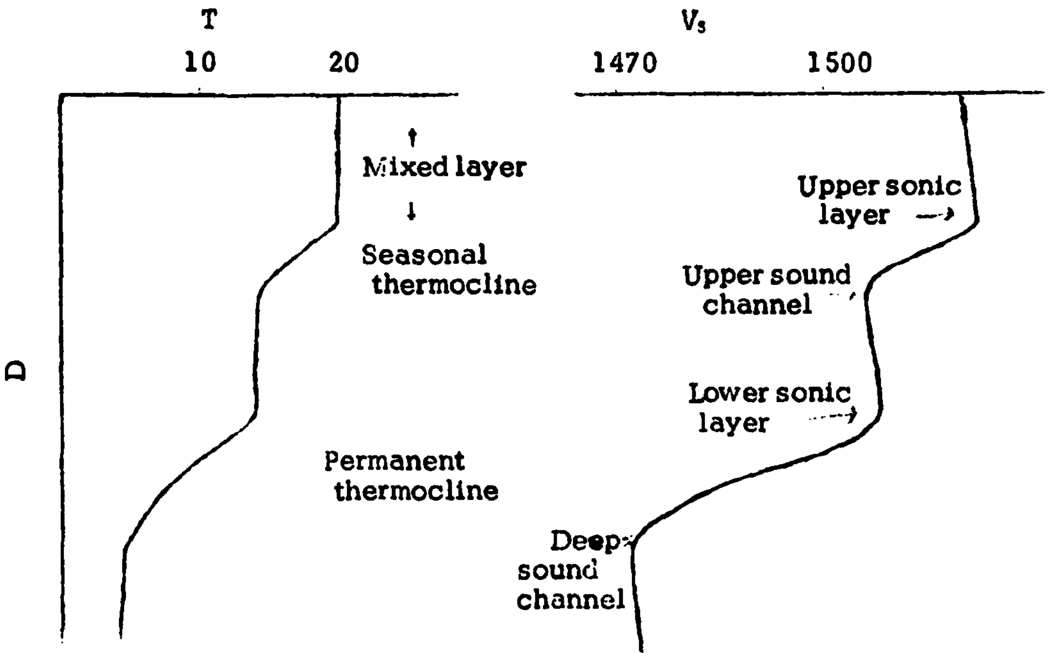
3. Continuous density models.



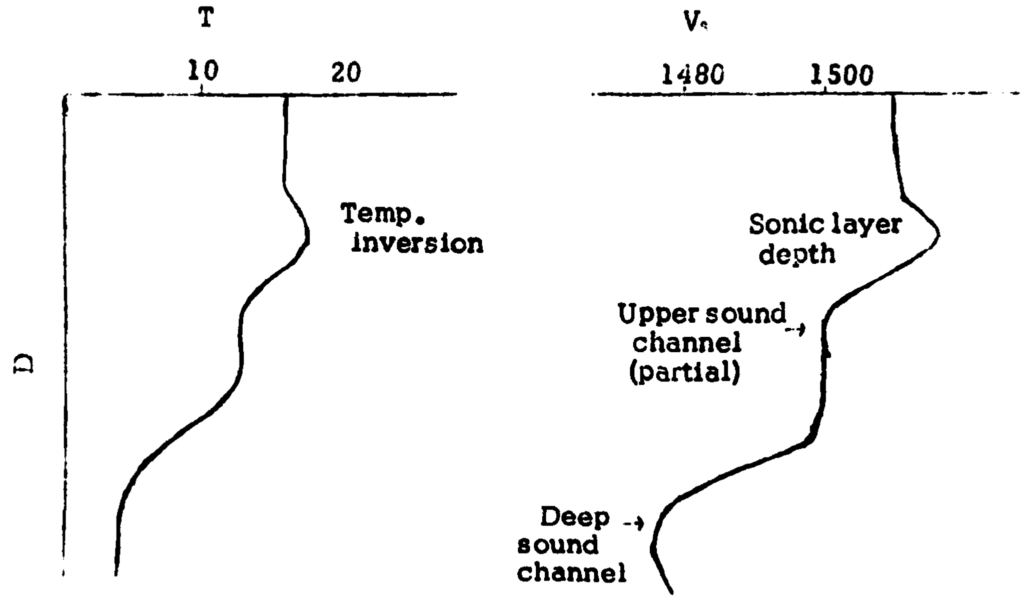
a) Prototype continuous density model (rare, in some upwelling and divergence areas).

b) Normal continuous density model (heating etc. in relatively calm weather conditions).

4. Secondary thermocline model.
(Seasonal or diurnal and permanent themoclines present)

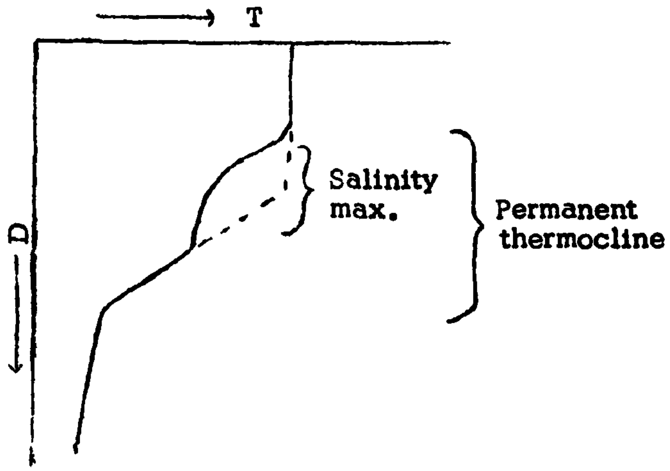


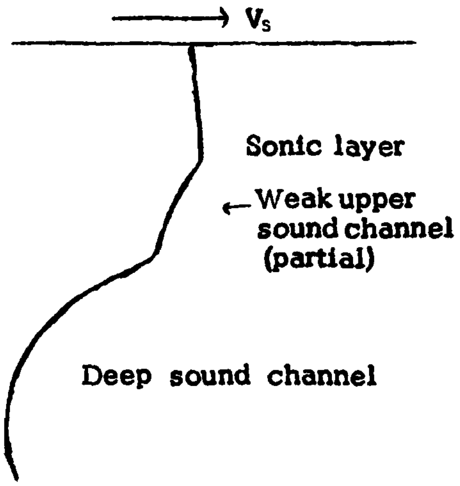
5. Temperature inversion.



There are, however, small changes of salinity with depth in the North Pacific, which are accompanied usually with specific temperature conditions. Two of these variations are of greater interest, and these models are given below.

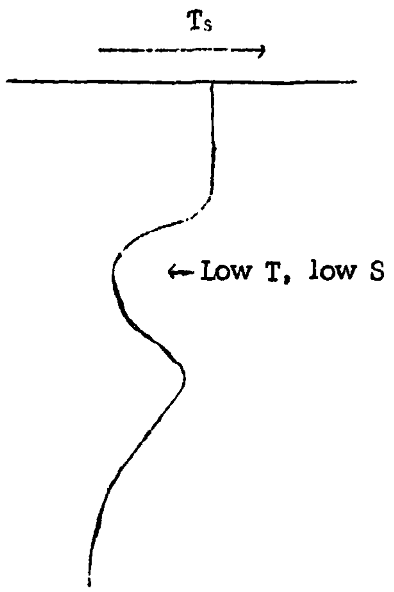
6. Salinity maximum layer in the upper part of permanent thermocline in NE Pacific (south of 35°N).

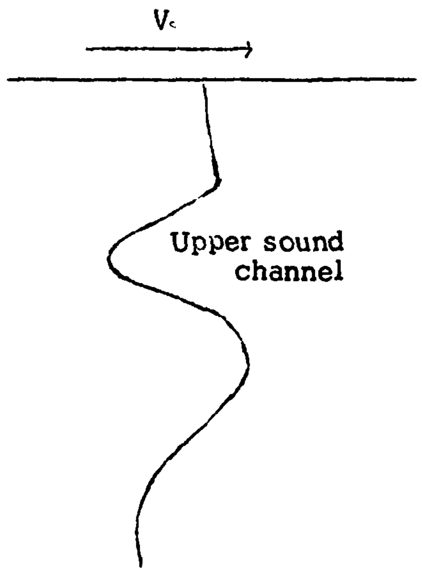




7. Salinity minimum and temperature minimum layer in the Oyashio area and south of the Aleutian Islands.

A low salinity, but cold (low temperature) water can be formed in the Bering Sea and along the Siberian coast. When this water is carried southward, especially with the Oyashio, it can be overrun with a warmer, more saline water. The resulting temperature structure can create a rather pronounced upper sound channel.





4. "Sound channels" and their effects on sound propagation in vertical and horizontal directions

Sound channels are layers with minimum sound speed. Low frequency sounds can be heard long distances in these sound channels because the sound rays (transmitted horizontally or nearly horizontally) bend back towards the lower velocity layer. The sound loss (and distance of propagation with little loss) depends on the nature of the channel (its "sharpness" and thickness etc.). On the other hand it is in certain conditions difficult (and/or impossible) to detect objects in the sound channel by vertical sounding from the surface (e.g., in case of the existence of a sharp sonic layer above the upper sound channel in case of a temperature inversion). The surface sound transmission loss through an upper daily sound channel may average 70% and more.

The depth of the main, deep sound channel varies but little seasonally except in some areas of convergence of major current systems (e.g., Kuroshio - Oyashio boundary). The average depth of this deep sound channel in the Pacific has recently been mapped for two seasons by R. Johnson in the Tsunami Research Unit in the University of Hawaii.

As seen from models in Section 3, the upper sound channel can exist only in certain conditions. Therefore its occurrence is somewhat "spotty" and temporal, determined mainly by vertical thermal structure. It could be assumed that this upper sound channel is of considerable interest to ASW; for example, for distant detection of enemy submarines, either by lowering of listening equipment into this channel or by locating surface detection ship into areas where the upper sound channel intersects the surface, and for avoiding of the sound channel by their own submarines.

As can be seen from the models in Section 3, the upper sound channel can exist only in certain defined conditions:

(1) through existence of a continuous density model with sufficient thermal gradient (caused by heating, overflow of warmer water or sometimes by upwelling as a result of divergence of surface currents)(Model 3).

(2) through existence of a secondary (seasonal and rarely diurnal) thermocline with sufficient thermal gradient (Model 4).

A "partial" upper sound channel may be created by other conditions, but this partial channel is probably not too efficient and therefore of lesser importance. (See Models 5, 6, and 7).

The areas of its intersection with the sea surface (which would be the best areas for "listening" by surface vessels without lowering gear into deeper water) are determined by surface temperature and subsurface thermal structure. Often these areas coincide with oceanic boundaries (current boundaries, divergence and convergence boundaries, etc.).

The existence and extent of the sound channels can be determined from thermal structure predictions. In Models 6 and 7 seasonal salinity structure could be included if higher accuracy is required.

## 5. Diurnal and other short-term changes of thermal structure

Diurnal heating can create a continuous density model and an accompanying upper sound channel near the surface (see Model 3 in Section 3). In terms of sound transmission this is called the "afternoon effect."

The magnitude of the diurnal effect varies seasonally from area to area and is determined by prevailing meteorological conditions, especially by winds and insolation.

According to observations of Dr. C. D'O Iselin (personal communication) the following rule of thumb can be arrived at: the seasonal thermocline forms (in the areas where the noon altitude of the sun is above 50°) if the cloudiness is less than five tenths and the wind speed is below 12 knots. Under higher cloudiness the insolation is too small for noticeable heating effects and in higher wind speed the mixing by waves distributes the additional heat over a thick layer, so that the heating effect is not clearly noticeable.

The internal waves and the surface divergence and convergence caused by the wind field or by large-scale eddies can disturb considerably the position and magnitude of the upper sound channel and cause it to intersect the surface (or in certain conditions to submerge into the deep sound channel).

## 6. Shortcut method for prediction of upper sound channel, its depth and its surface intersection areas

The hydroclime information in the enclosed appendix by Pattullo and Cochrane shows the areas where upper sound channels occur in spring months. As the occurrence of the upper sound channel is spotty and temporal, it should be predicted on a daily basis, which will be done from next season on by the Fleet Numerical Weather Facility.

A shortcut method for prediction of the presence of an upper sound channel is at times useful. It consists of comparing the adjusted hydroclime temperature at the upper boundary of the permanent thermocline with the actual sea surface temperature. When and where this temperature difference is $> +1^\circ F$, the presence of an upper sound channel can be expected. The depth of the upper boundary of this channel can be estimated by multiplying the highest significant wave heights during the past few days by 12.5.

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UNIVERSITY OF CALIFORNIA
SCRIPPS INSTITUTION OF OCEANOGRAPHY

# MONTHLY THERMAL CONDITION CHARTS
# FOR THE
# NORTH PACIFIC OCEAN

This atlas is the third of a special series of oceanographic reports prepared by Scripps Institution of Oceanography containing the results of work carried out for the Hydrographic Office and the Office of Naval Research of the Navy Department, under contract with the University of California.

Navy Department
Contract No.
N6-onr-275
Task Order 12

MSS
~~Confidential~~ Report No. 3
June G. Pattullo and
John D. Cochrane
Bathythermograph Section
April 1951

~~Confidential~~
ONR-416
June 21, 1960

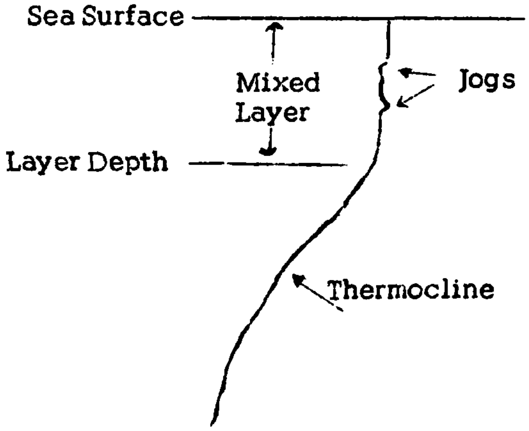
## INTRODUCTION

This atlas contains charts of the North Pacific Ocean showing average monthly conditions of two parameters that influence the transmission of sound in the sea. These charts were compiled by the Bathythermograph Section, Scripps Institution of Oceanography, La Jolla, California, under contract with the Navy Department.

The chief direct source of data used was the more than 100,000 bathythermograph observations taken in this ocean by vessels of the United States Navy, United States Coast Guard, and civilian research activities. The area covered extends from the equator to latitude 60°N., except in the Bering and Okhotsk Seas, where in most months data are too few to provide reliable averages. In some other regions the contours on both sets of charts are questionable because observations are very scarce. This is particularly true in low latitudes in the eastern part of the ocean.

## LAYER DEPTH

Layer depth, as given on the right hand chart of each monthly pair, represents the depth to the top of the seasonal thermocline, or the permanent thermocline where the seasonal thermocline is absent. A thermocline is a rapid decrease of temperature with depth, or the depth interval over which this decrease takes place. One or a few slight jogs in the trace do not constitute a thermocline; there must be a continuous decrease of temperature. The layer depth, then, is not necessarily the depth of isothermal water, but small negative or positive gradients may be present above it.



Such small irregularities in the trace are usually short-lived, not persistent physical boundaries in the water column. For this reason the name "mixed layer" is applied to the entire column of water above the top of the thermocline. The figure shows these features as they appear on the BT trace.

### Seasonal Thermocline

In the open oceanic regions, outside of the tropics, a regular annual cycle of thermocline formation and deepening occurs. The term "seasonal thermocline" is applied to the thermocline that follows this regular cycle. There may be other thermoclines present in the

water column sampled by the BT, as many as 3 or even 4 can sometimes be seen. But the seasonal thermocline appears regularly on the observations and is the one for which the contours are drawn in these regions.

It appears at 50 to 150 feet in April to June, and becomes stronger and somewhat deeper during the summer. Then (usually after October) it deepens rapidly until it disappears below BT depth in December to March. This is similar to the annual cycle observed in the North Atlantic Ocean (Monthly Thermal Condition Charts for the North Atlantic Ocean, H.O. Pub. 569-A, CONF.).

This schematic picture varies considerably with position. In the open ocean the most important factor on a parallel of latitude is season, while near coasts it is the influence of the land. In certain regions, such as that of the Kuroshio Current (hatched lines on the TEMPERATURE DIFFERENCE charts), the strong flow of the currents gives rise to a complicated, irregular thermal structure. We consider the seasonal variation under each of these three regimes in turn.

<u>Oceanic Regions. Spring (Stippled Areas)</u>. The first evidence of the new seasonal thermocline is the appearance of small irregularities in the BT trace, some of which include a continuous temperature decrease of several degrees and therefore rate the name of thermocline. However, there depths are variable; in any arbitrary observation they may appear anywhere in the water column. These areas where spring heating is complicating the more simple winter structure have been stippled on the charts from February through May. On the average in these regions the layer depth is deep, but between 20 and 50 percent of the time it is found somewhere above the contour depth, because of the formation of some weak new thermocline or thermoclines above the old one.

The stippled area in February is only a small region west of Hawaii. It spreads rapidly northward and in its east-west extent, and moves to higher latitudes as summer approaches. By June the new seasonal thermocline has become well established as far north as our data go, and the stippled area no longer appears.

<u>Oceanic Regions. Early Summer (Dashed Contours)</u>. In early summer (April and May, usually) the new seasonal thermocline appears more and more frequently, so that for a large percentage of the time its depth determines the layer depth. This is shown on the charts by using dashed contours for the old, deep layer depth, and solid contours for the new, shallow one. It means that between 50 and 80 percent of the time the layer depth is the depth to the new seasonal thermocline, as indicated by the solid lines. But between 20 and 50 percent of the time this thermocline is not present, so the layer depth is that shown by the dashed contours.

For example, in April, at 30°N., 140°W., the shallow value is between 150 and 200 feet, if we estimate it from the solid 150 foot contour in Figure 9. The deeper value (dashed lines) is 400 feet or greater. At the same time we see that this position is just about on the edge of the stippled region. This means that about 50 percent of the time the layer depth is near 150 feet, about 50 percent of the time it is greater than 400 feet.

Over most of the ocean both levels are important at some time during each year. Since the purpose of these charts is to estimate the actual depth to the top of the first real thermocline, contours are provided for both levels rather than an "average" of observed positions. In early summer the arithmetic mean frequently falls between the two likely positions of the layer depth and contours of its value might be misleading.

Figure 1A. shows a graph to illustrate this point. All the observations taken in May 1947 at the weather station at 49°N., 148°W. were used. During this period the shallow seasonal thermocline was already well developed and the "deep" thermocline was not as deep as usual, so the data provide a particularly good example of the two layer depths. There was generally a layer depth near 100 feet (92 percent of the time between 75 and 150 feet). There was also usually a deeper thermocline (80 percent of the time between 275 and 450 feet). But the average value falls between 175 and 200 feet, where a thermocline, and therefore the layer depth, actually appeared only 1 percent of the time.

The dashed contours appear on the charts during only two months: April and May. They follow the stippled area in spreading northward and in longitudinal extent, as is to be expected, since they represent the second phase in formation of the seasonal thermocline. Because the new thermocline is established by June, the dashed contours disappear just as the stippled area does.

Oceanic Regions. Mid-Summer through Winter. From June until the re-appearance of the stippled area in February, the same seasonal thermocline dominates the layer depth pattern in this region north of the tropics, and its depth is indicated by the single set of solid contours. Its annual cycle has been discussed above. It is shallowest in middle and high latitudes in June and July and deepest in the same parts of the ocean in February and March.

Near Coasts. Near coastlines the seasonal trends, in general, are similar to those that apply at the same latitudes in the open ocean, but the layer depths are considerably shallower. This means that in spring the shallow new thermoclines are distributed over a smaller vertical water column. In these regions, therefore, the contouring is continuous and no effort has been made to characterize the spring effect.

Currents (Hatched Region). Whenever a strong current appears the thermal structure becomes quite complicated and the simple picture of a more or less mixed layer above a smooth thermocline is no longer accurate. This effect is especially noticeable in the region of the Kuroshio Current, off Japan. Contours have been drawn as for the rest of the ocean, but the area has been hatched on the TEMPERATURE DIFFERENCE charts to indicate the great variability observed there.

### Permanent Thermocline

In the tropics the regular seasonal cycle does not appear, and the thermocline lies at about the same average depth throughout the year. Its depth from observation to observation varies considerably with internal waves and the effects of currents, but little change is noted from month to month. It is then called a permanent thermocline and its depth is the one contoured on the charts in low latitudes. There is also a permanent thermocline in higher latitudes, but usually the mixed layer does not extend down to it.

### TEMPERATURE DIFFERENCE, SURFACE TO 30 FEET

The left hand chart of each monthly pair shows the average temperature difference, in degrees Fahrenheit, between the surface and 30 feet. This is an extremely variable quantity since it is under the direct influence of the meteorological conditions. Figure 1B. is a graph of the differences observed during July 1946, at 30°N., 140°W. It shows that the difference is zero a large percentage of the time, which is typical of all the months and locations examined. The presence of a few high values gives the average a value greater than zero, in this example about 0.7°F. Ordinarily in July at 30°N., 140°W. it is considerably less than this (Figure 14.).

As mentioned above, the hatching off Japan indicates the region of the Kuroshio Current, where conditions are variable at all seasons. In winter this region and the area between it and the Asiatic coast have very frequent negative temperature differences. That is, for 10 to 30 feet the temperature increases with depth below the surface (positive temperature gradients).

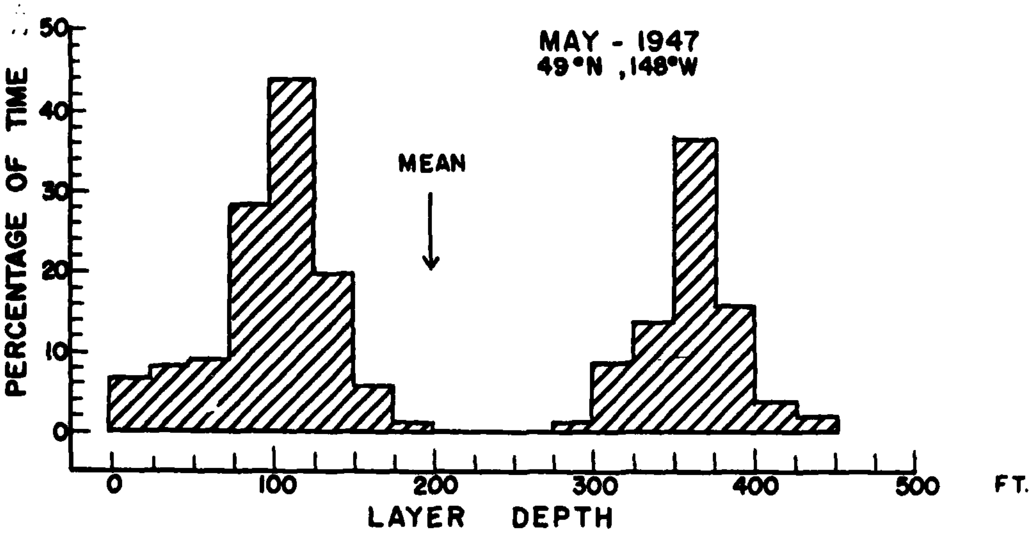

MAY - 1947
49°N ,148°W
MEAN
PERCENTAGE OF TIME
0
10
20
30
40
50
0
100
200
300
400
500
FT.
LAYER DEPTH

Fig. 1a

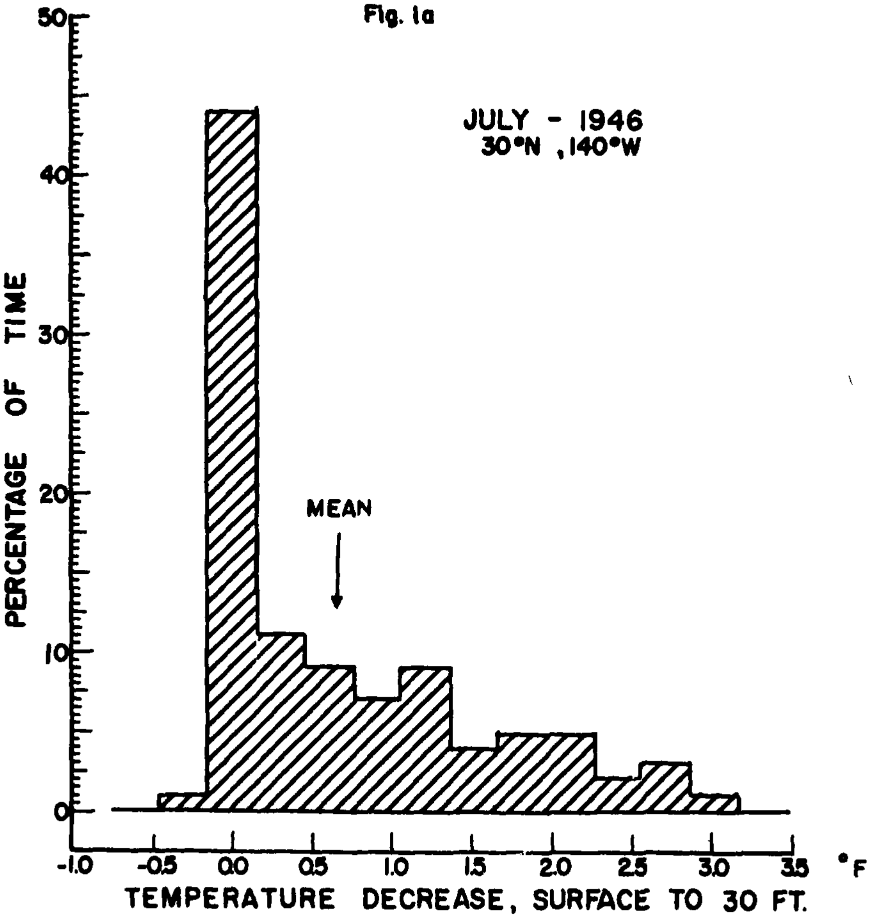

JULY - 1946
30°N ,140°W
MEAN
PERCENTAGE OF TIME
0
10
20
30
40
50
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
°F
TEMPERATURE DECREASE, SURFACE TO 30 FT.

Fig. 1b

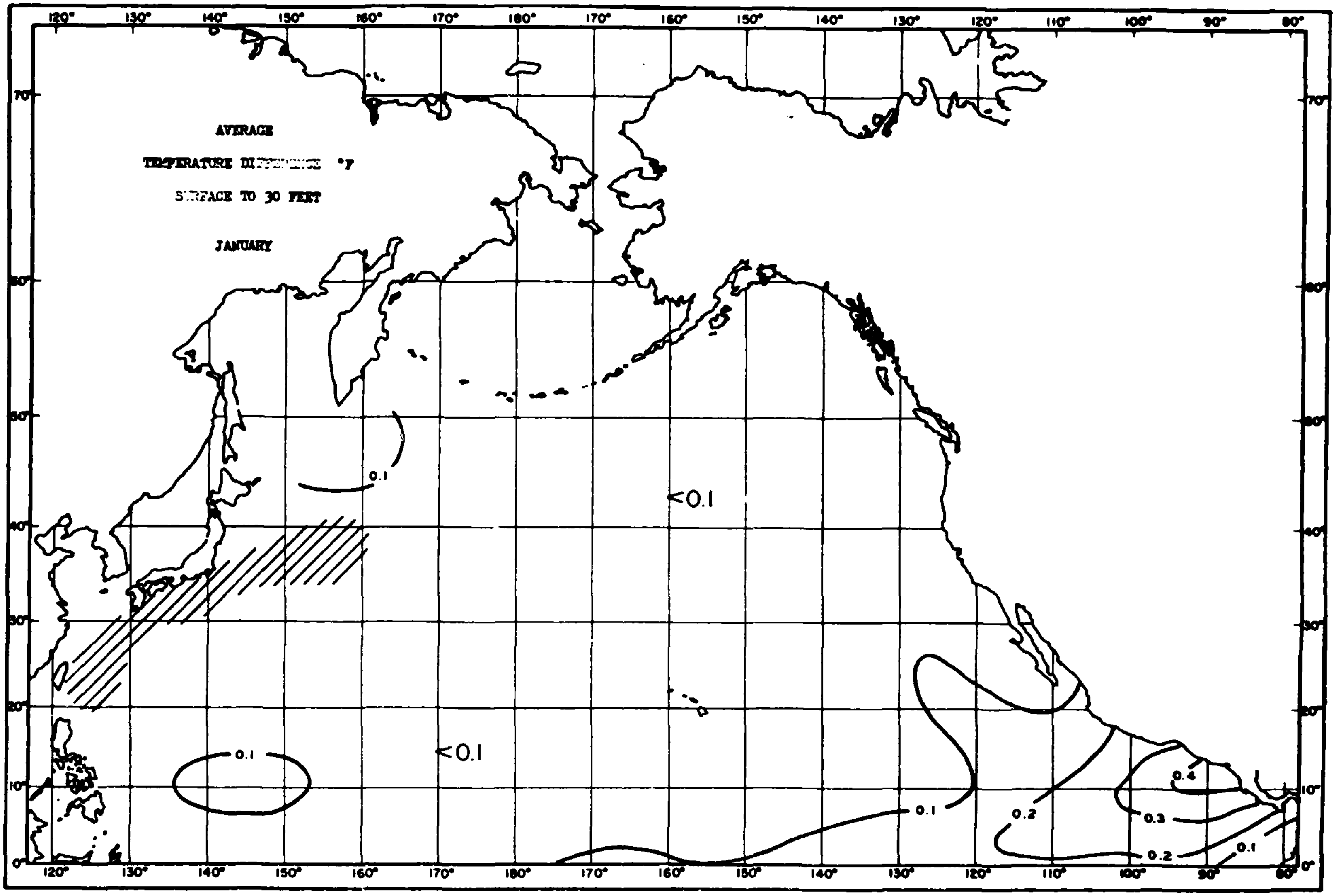

AVERAGE
TEMPERATURE DIFFERENCE °F
SURFACE TO 30 FEET
JANUARY
<0.1
<0.1
0.1
0.1
0.1
0.2
0.2
0.3
0.4
0.1
0.2
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
70°
60°
50°
40°
30°
20°
10°
0°

Figure 2.

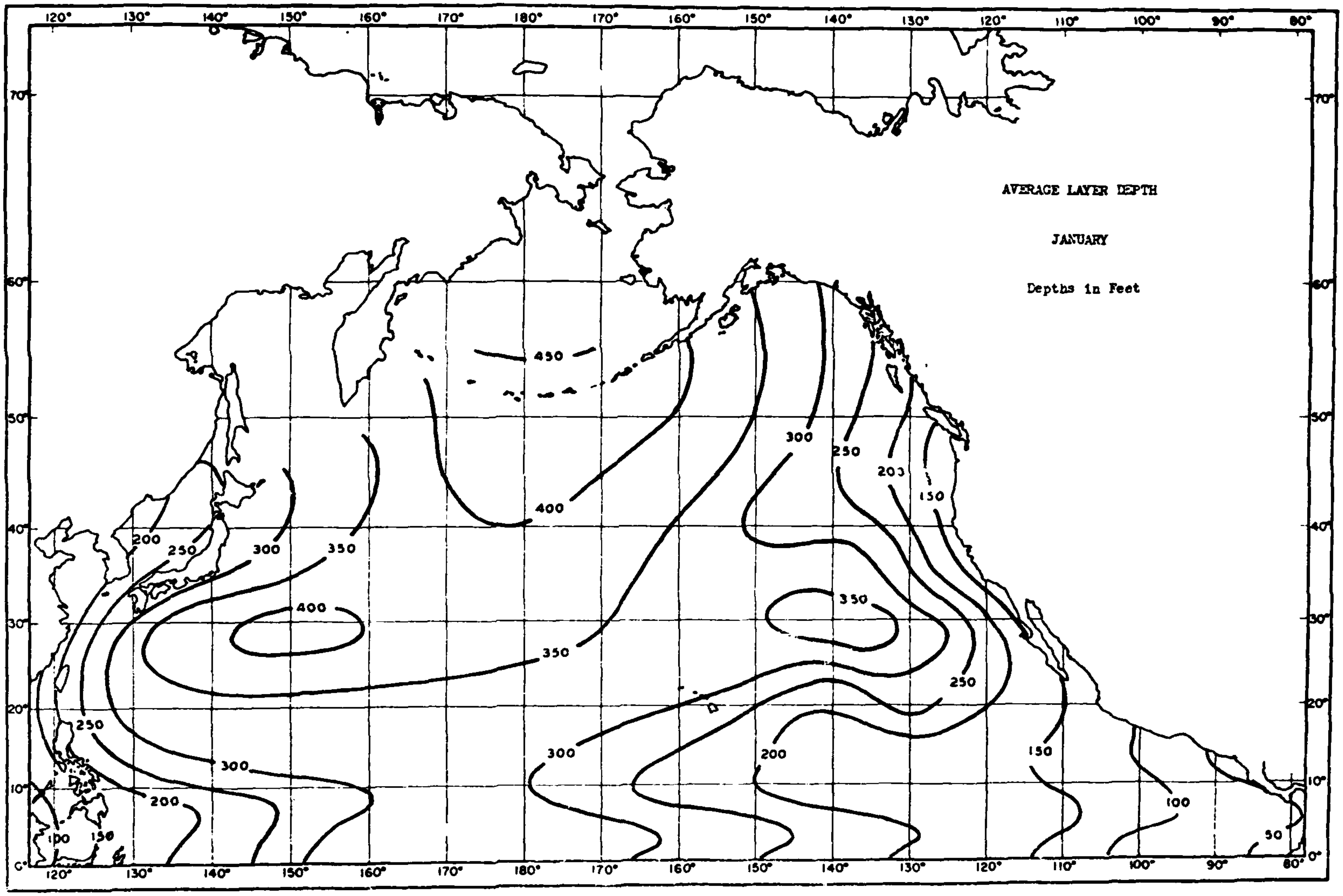


Figure 3.

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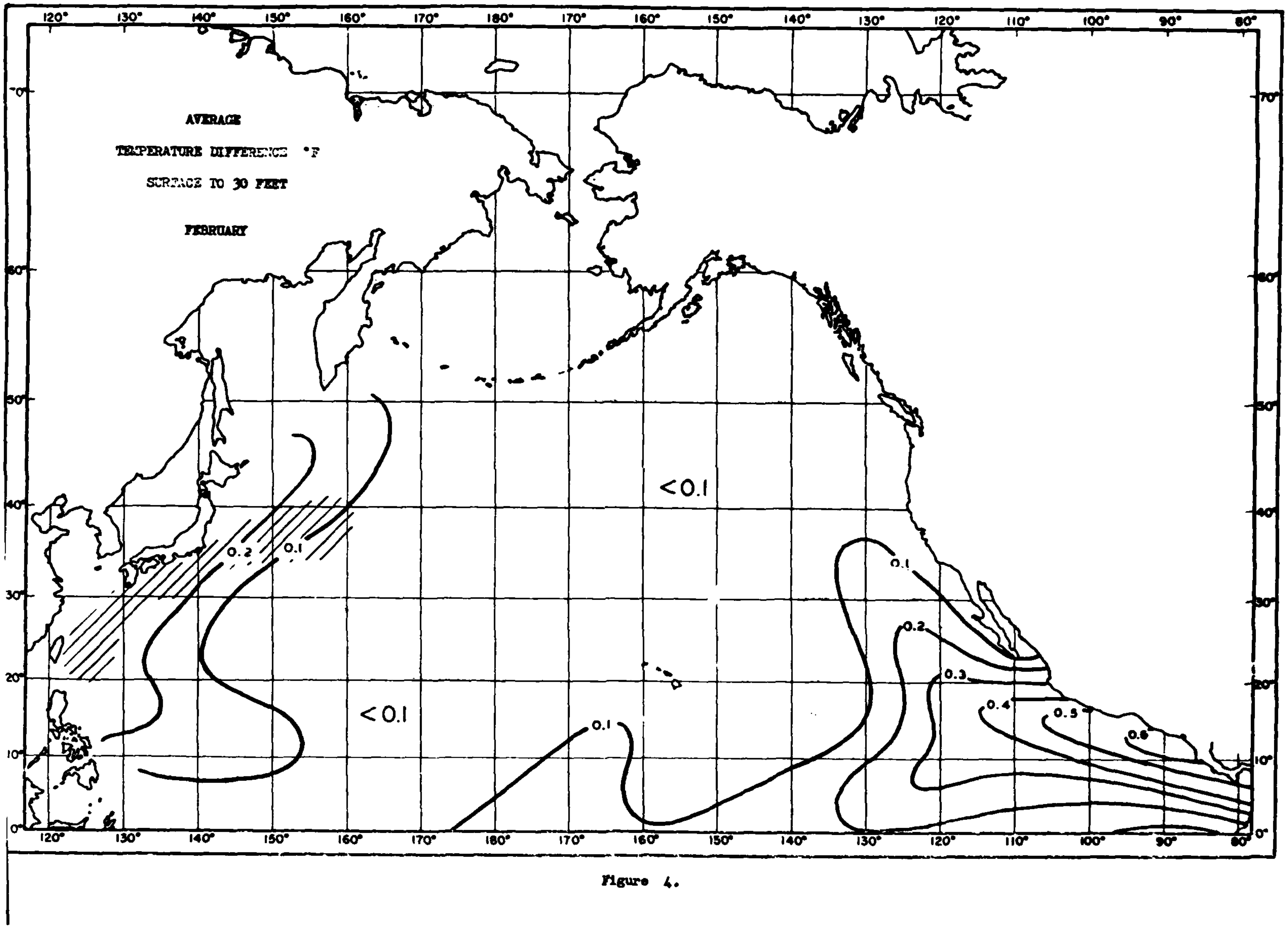

AVERAGE

TEMPERATURE DIFFERENCE °F

SURFACE TO 30 FEET

FEBRUARY

Figure 4.

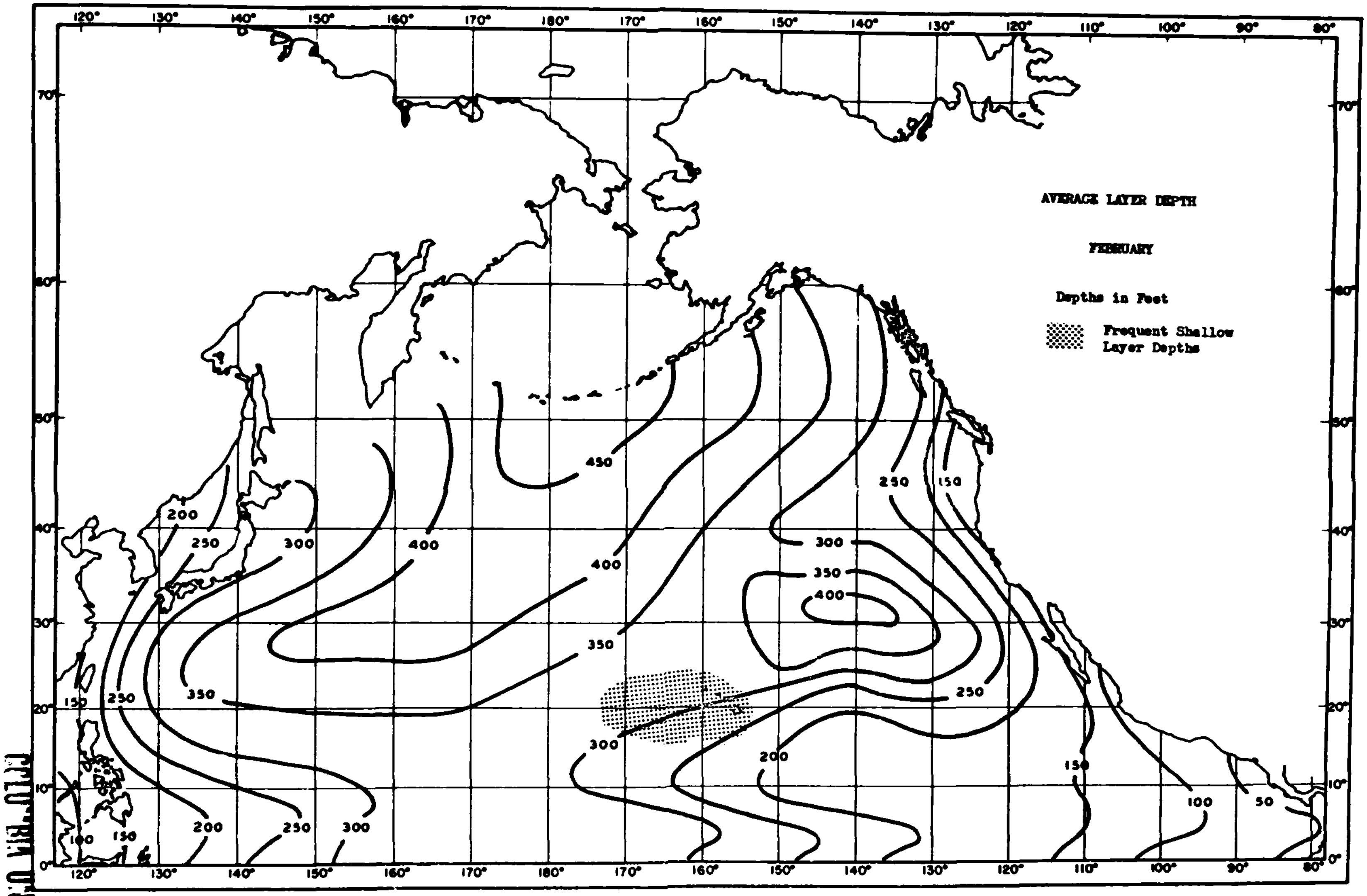

Figure 5.

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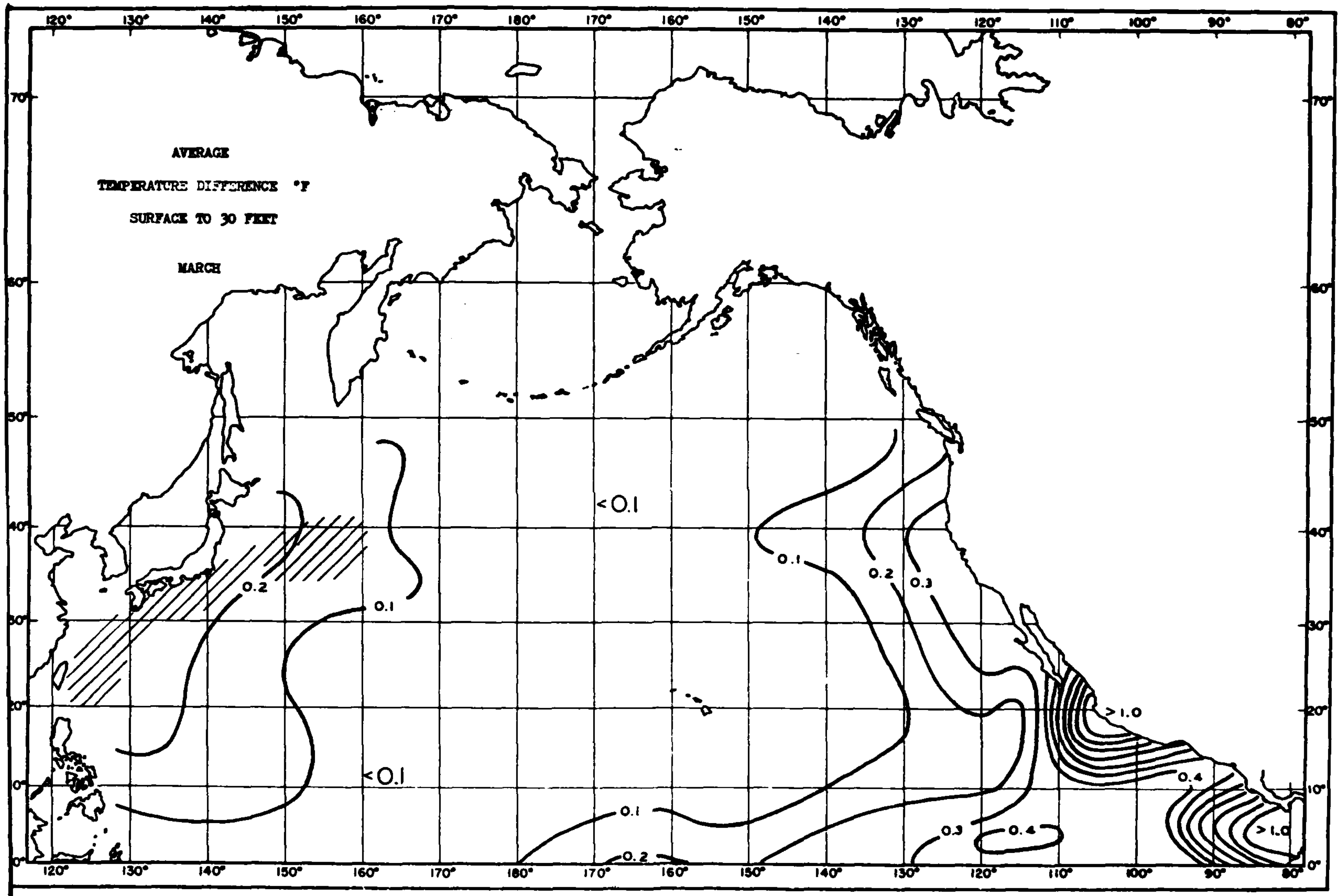
AVERAGE
TEMPERATURE DIFFERENCE °F
SURFACE TO 30 FEET
MARCH
<0.1
<0.1
0.1
0.1
0.1
0.2
0.2
0.2
0.3
0.3
0.4
0.4
>1.0
>1.0
120°
130°
140°
150°
160°
170°
180°
170°
160°
150°
140°
130°
120°
110°
100°
90°
80°
0°
10°
20°
30°
40°
50°
60°
70°

Figure 6.

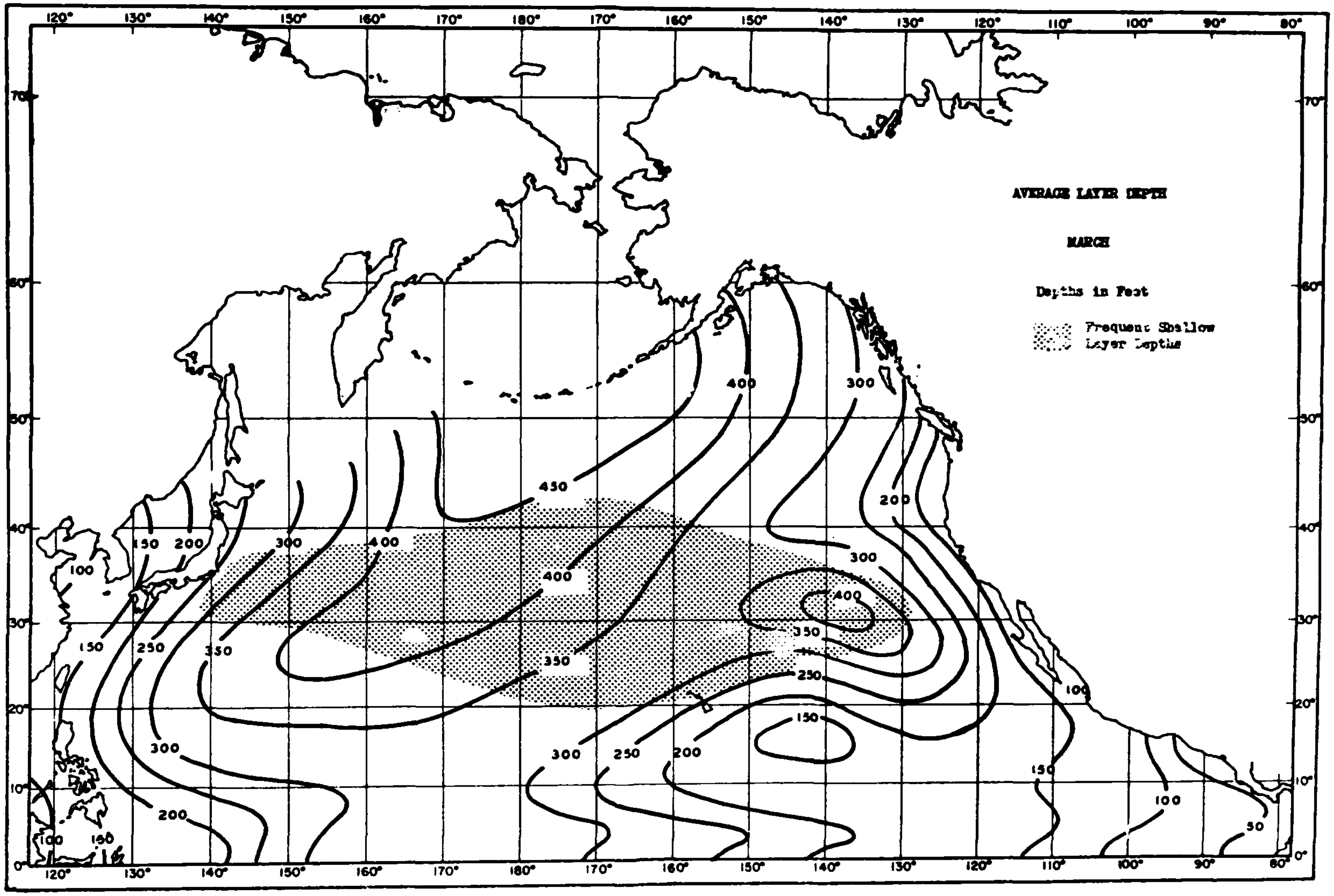

Figure 7.

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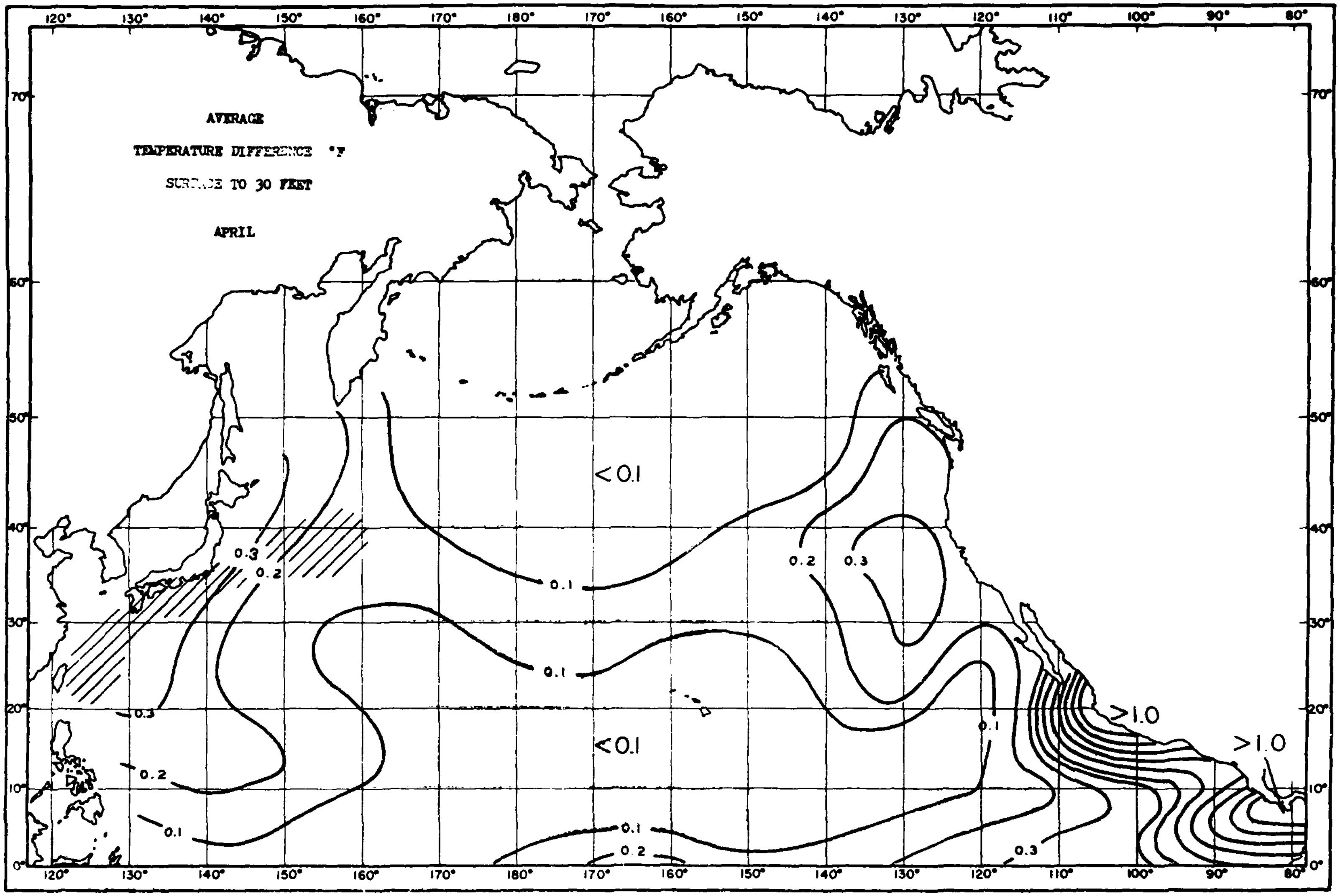

Figure 8.

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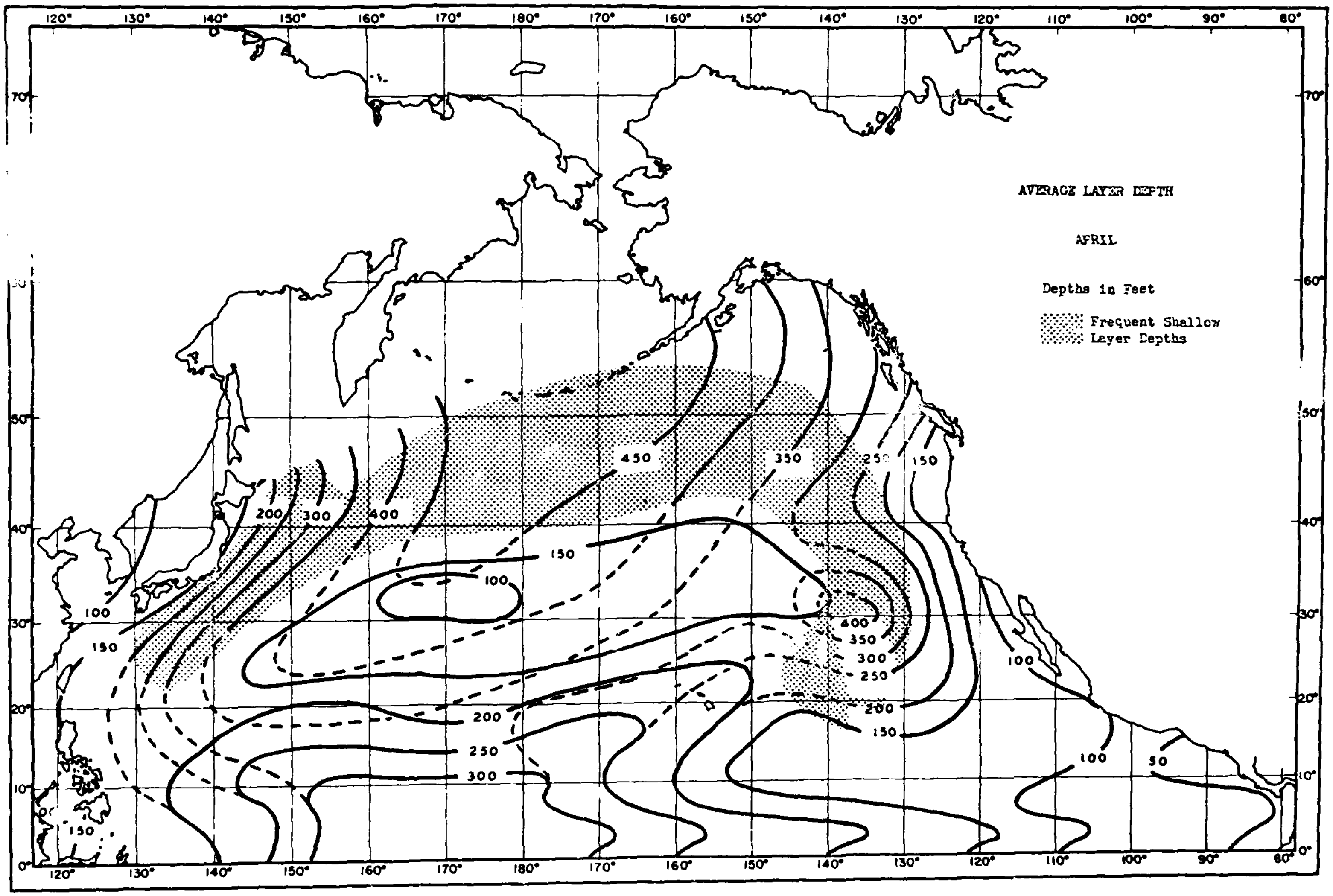

Figure 9.

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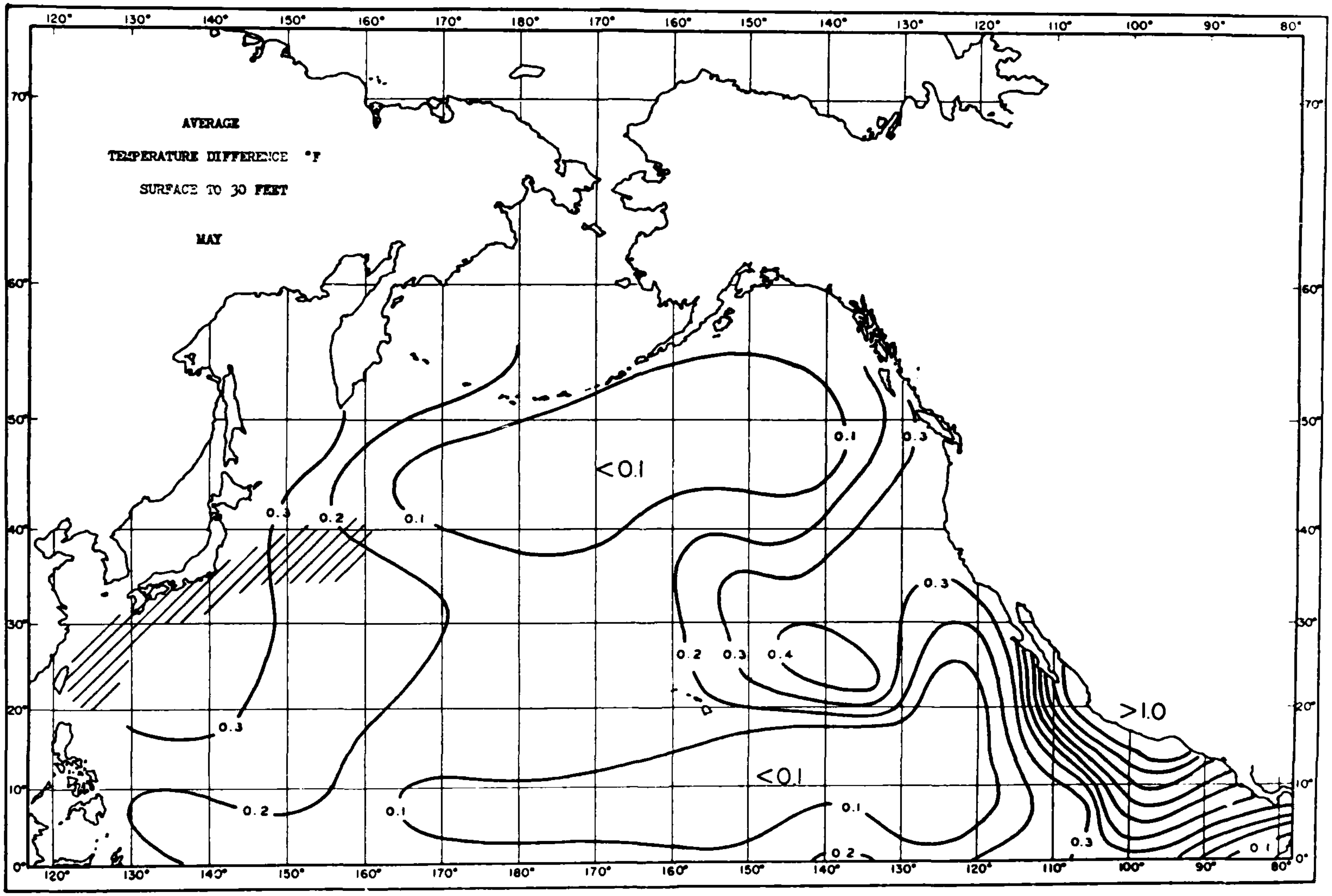

Figure 10.

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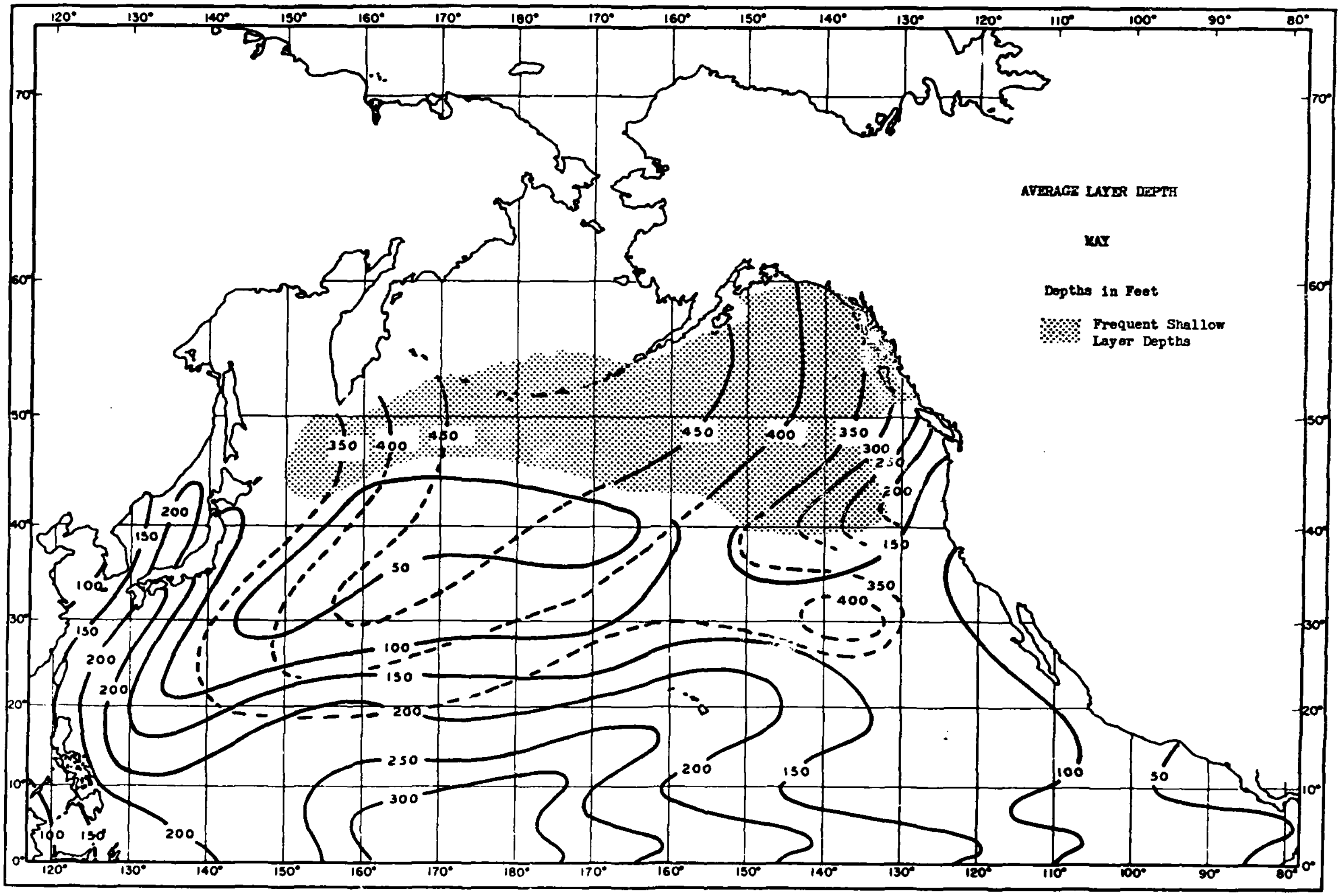

Figure 11.

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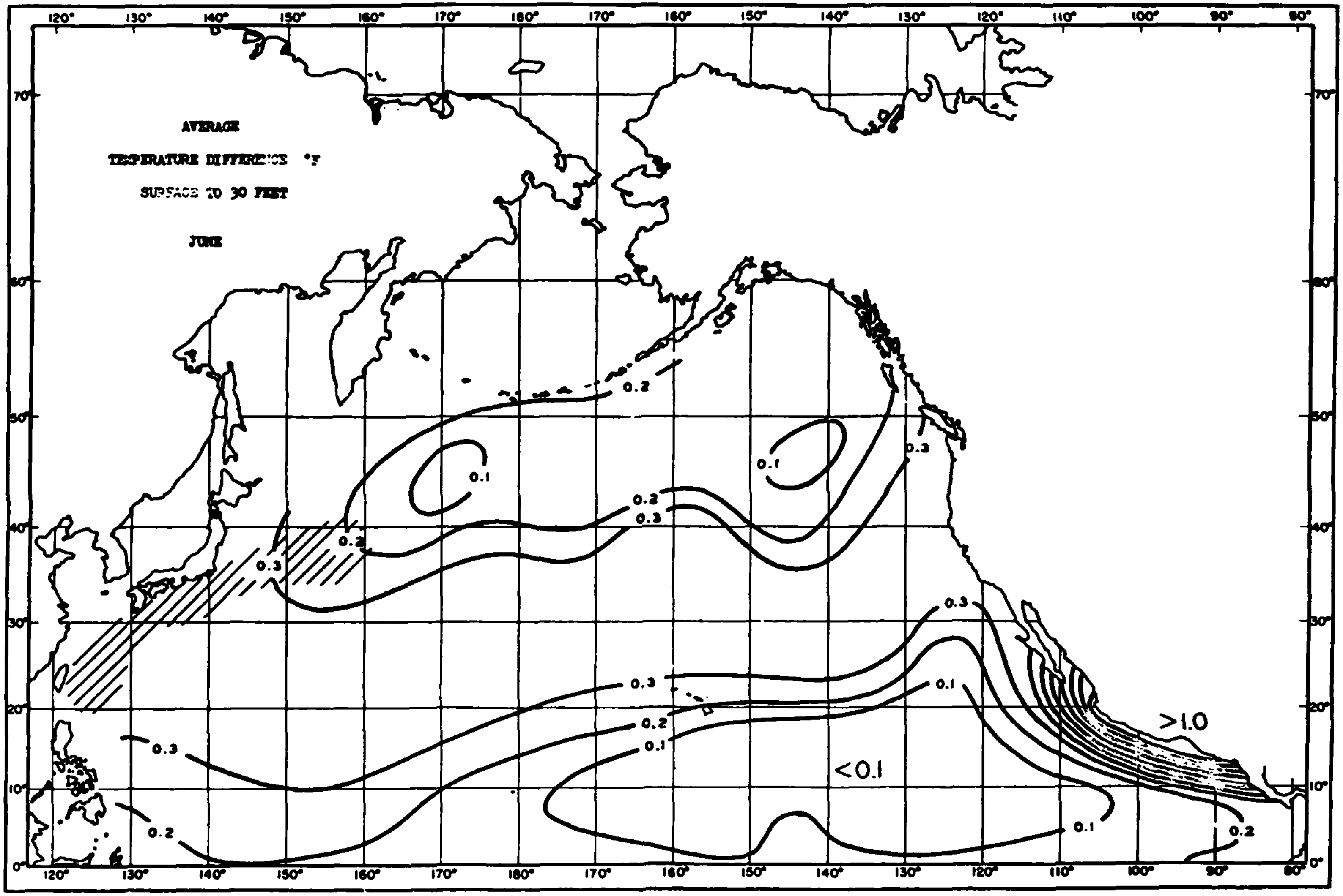

Figure 12.

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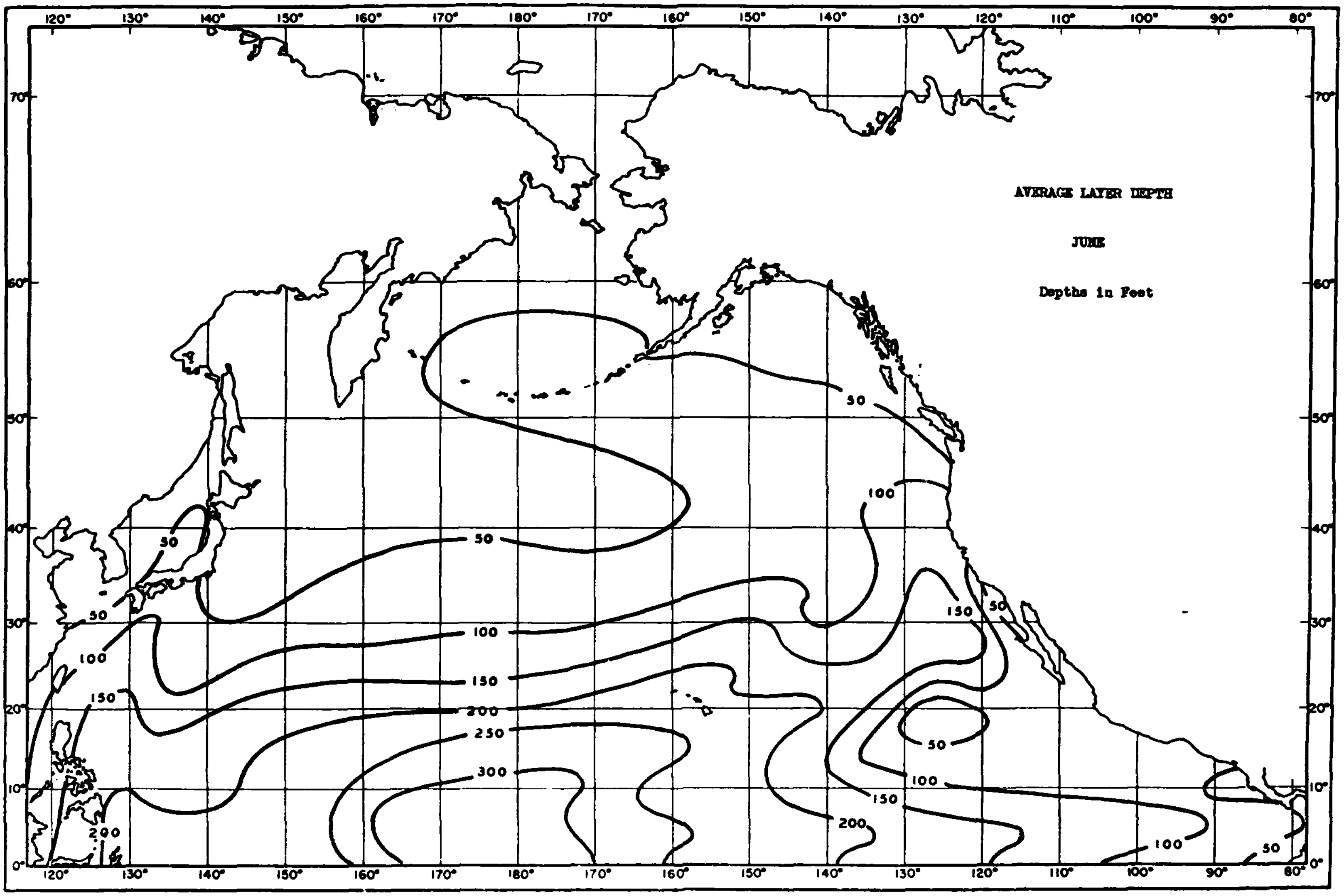

Figure 13.

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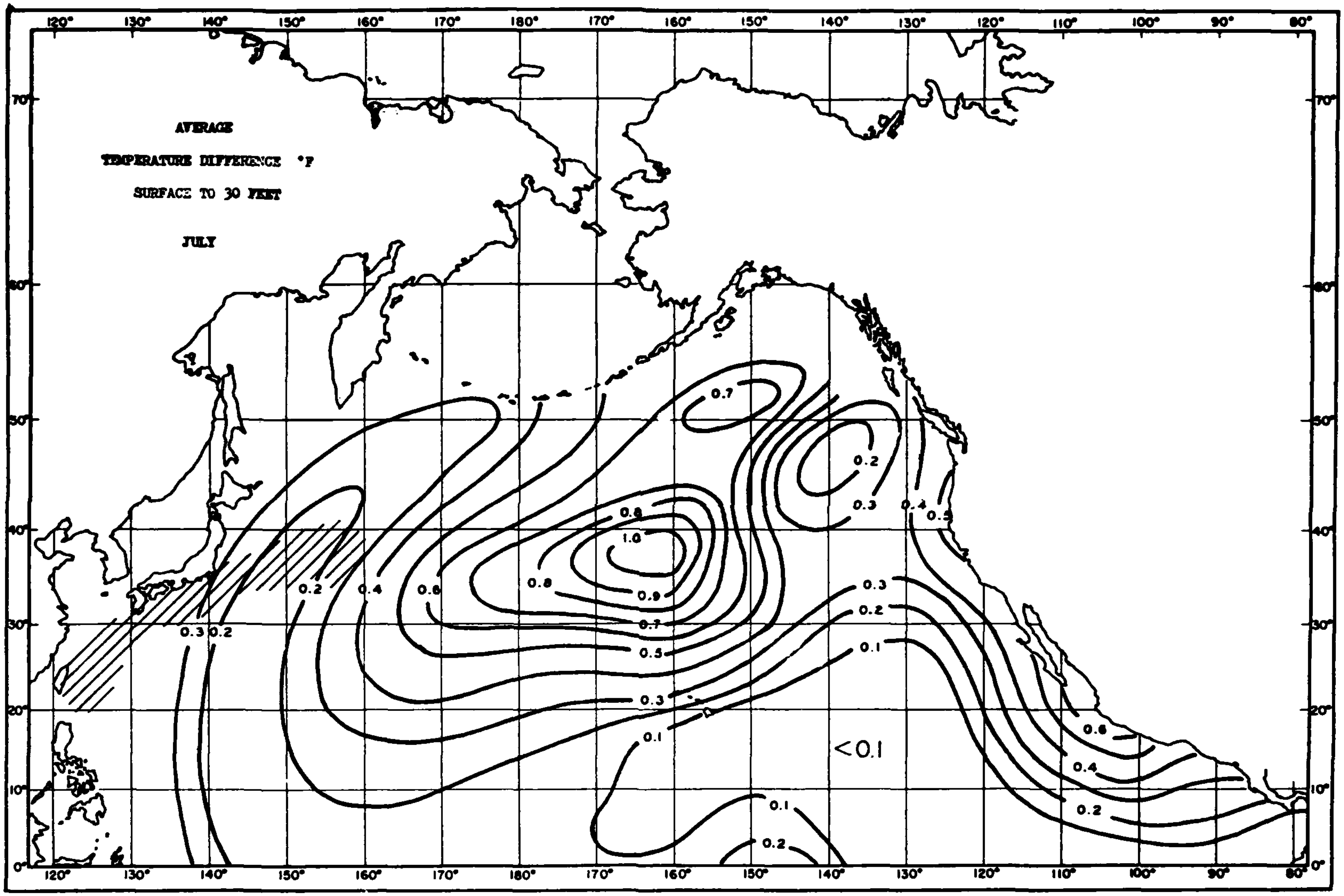

Figure 14.

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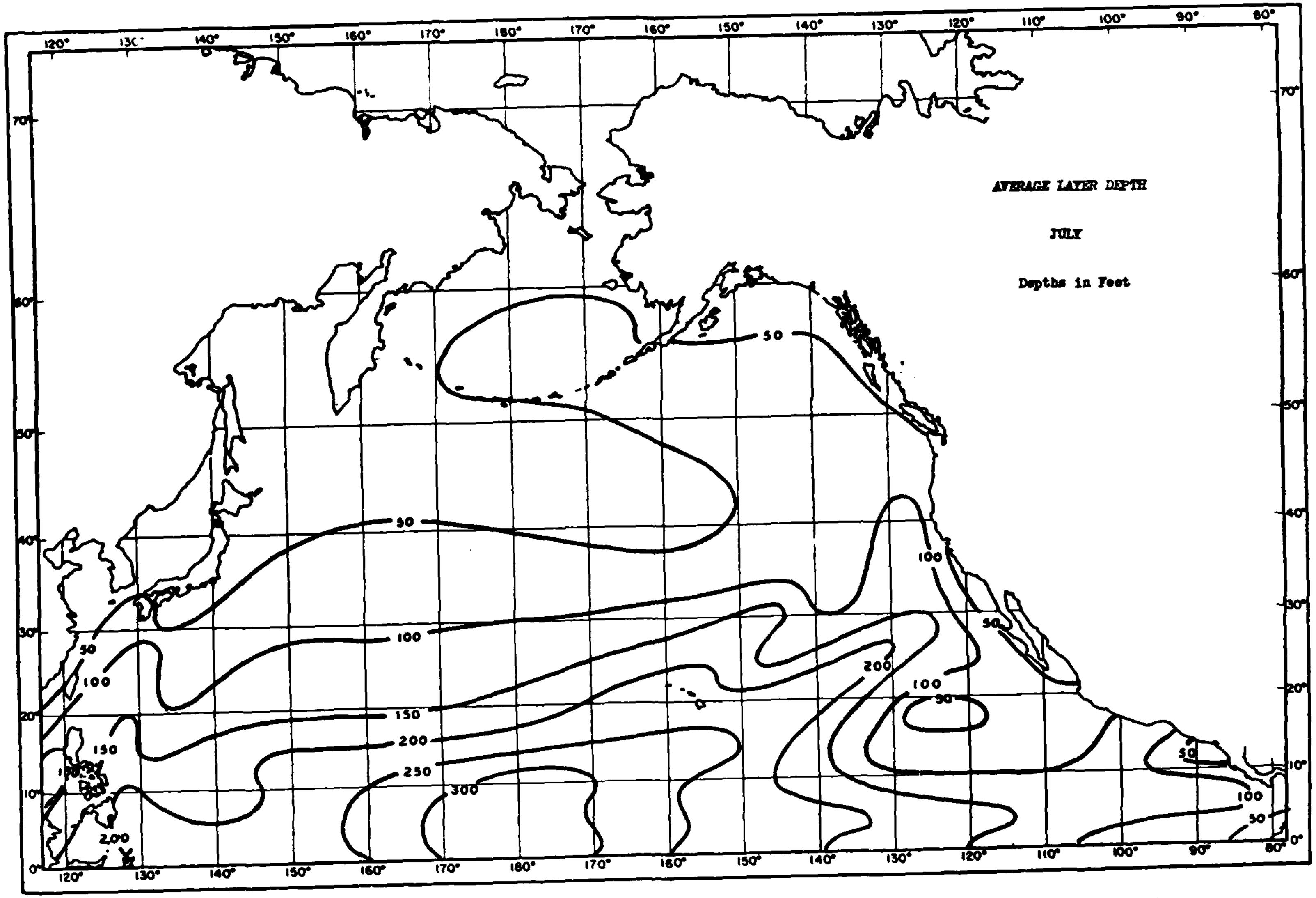
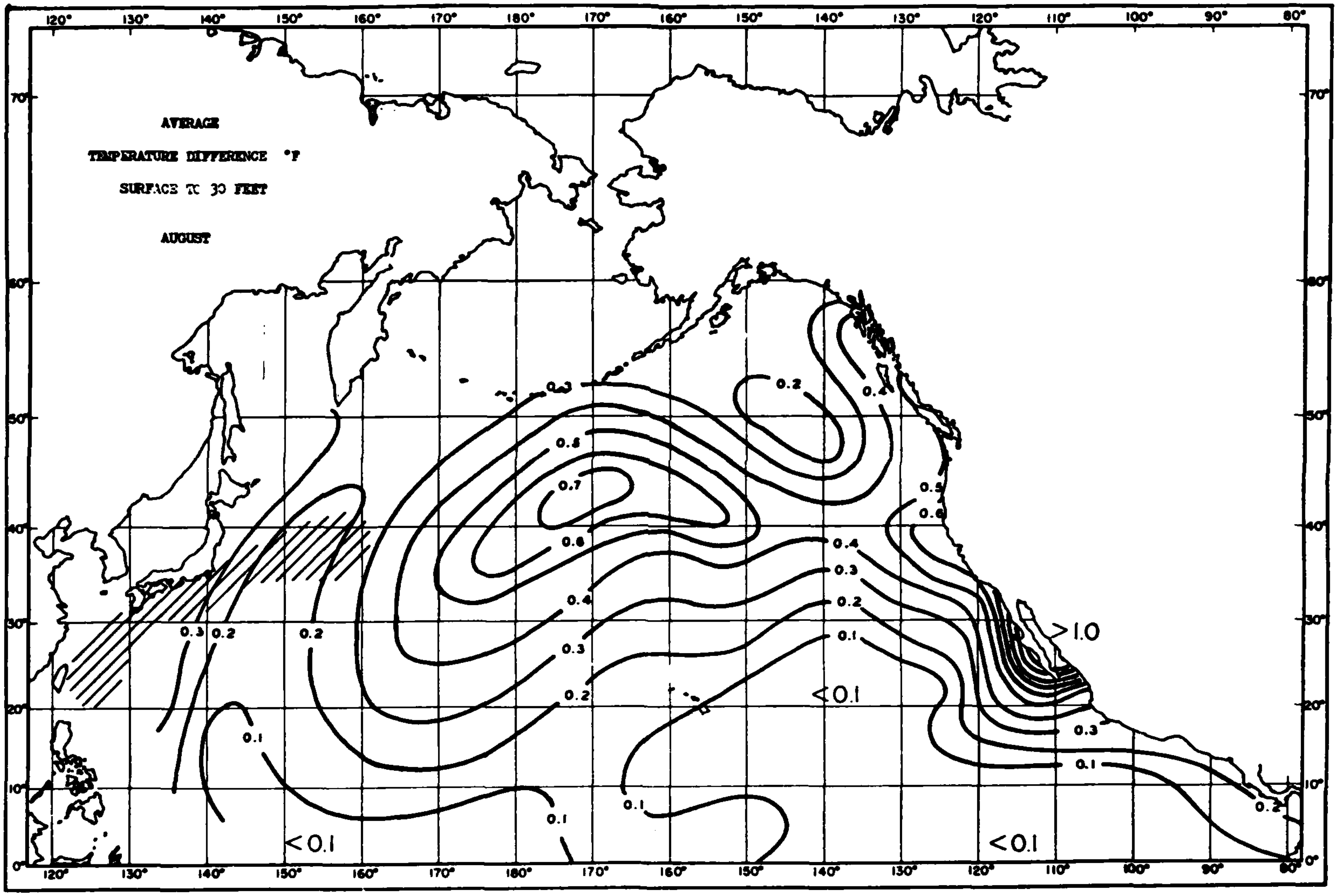


Figure 15.

ONR 416
6/21/60



AVERAGE

TEMPERATURE DIFFERENCE °F

SURFACE TO 30 FEET

AUGUST

Figure 16.

ONR 416
6/21/60

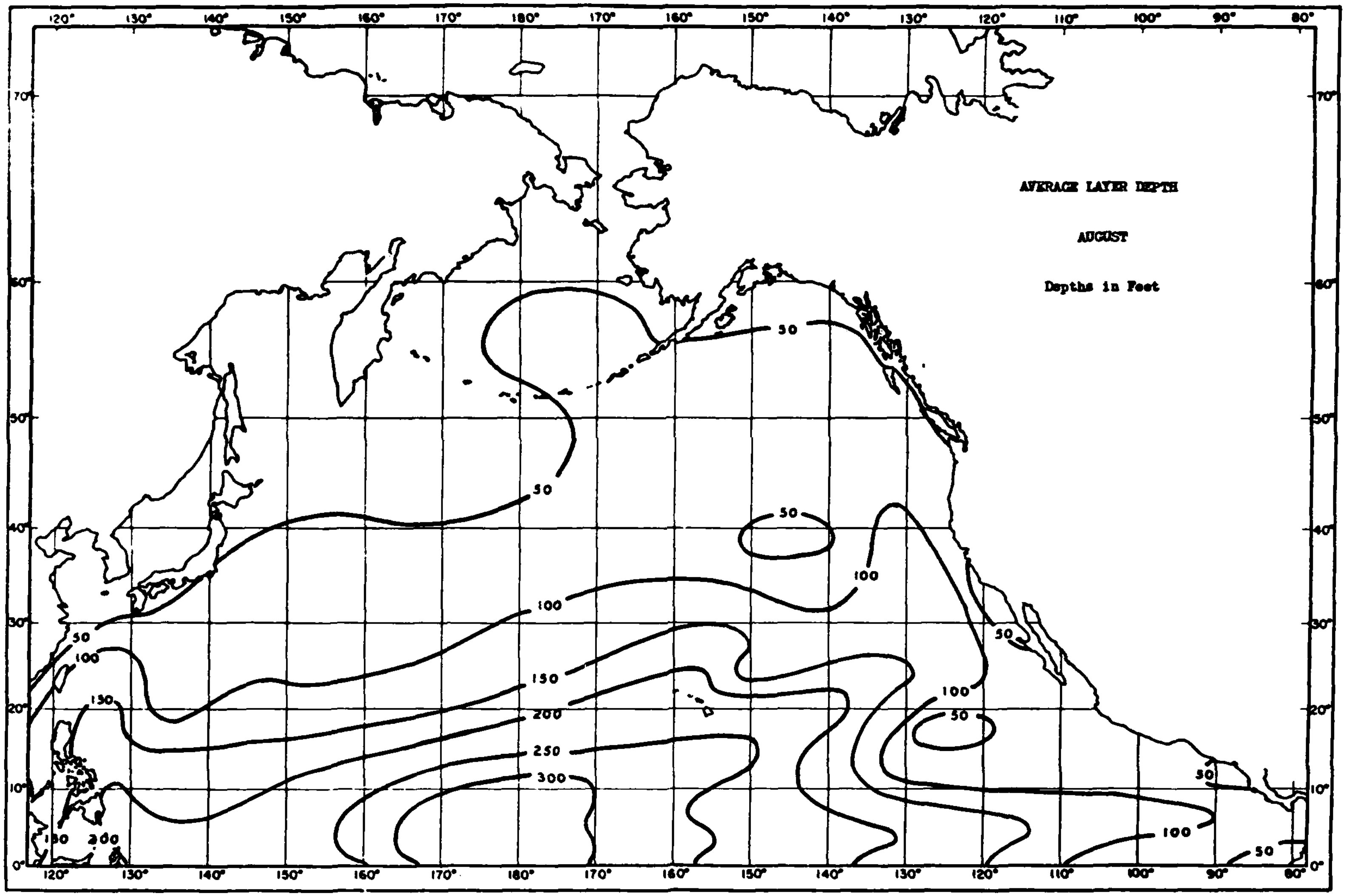


Figure 17.

ONR 416
6/21/60

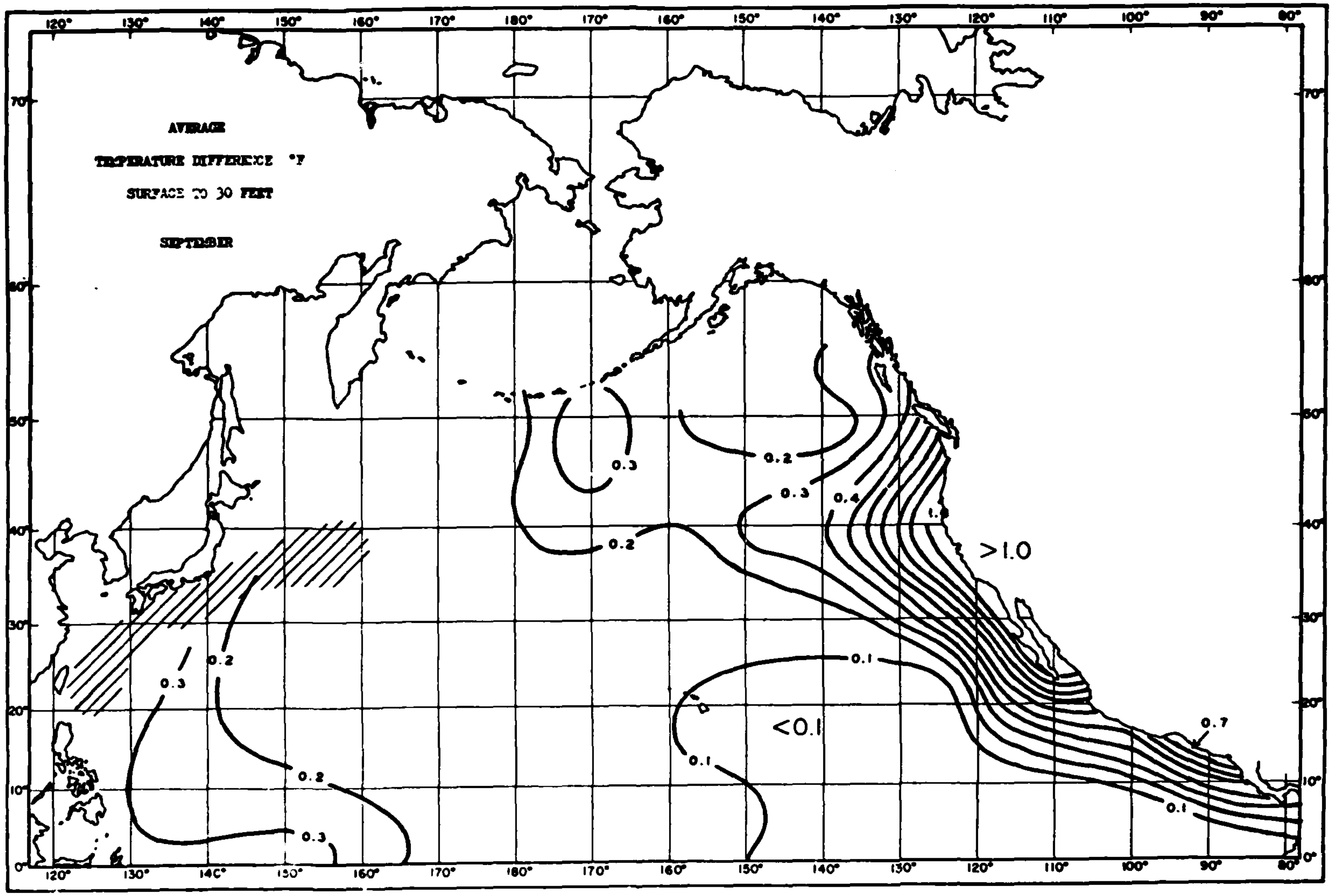


Figure 18.

ONR 416

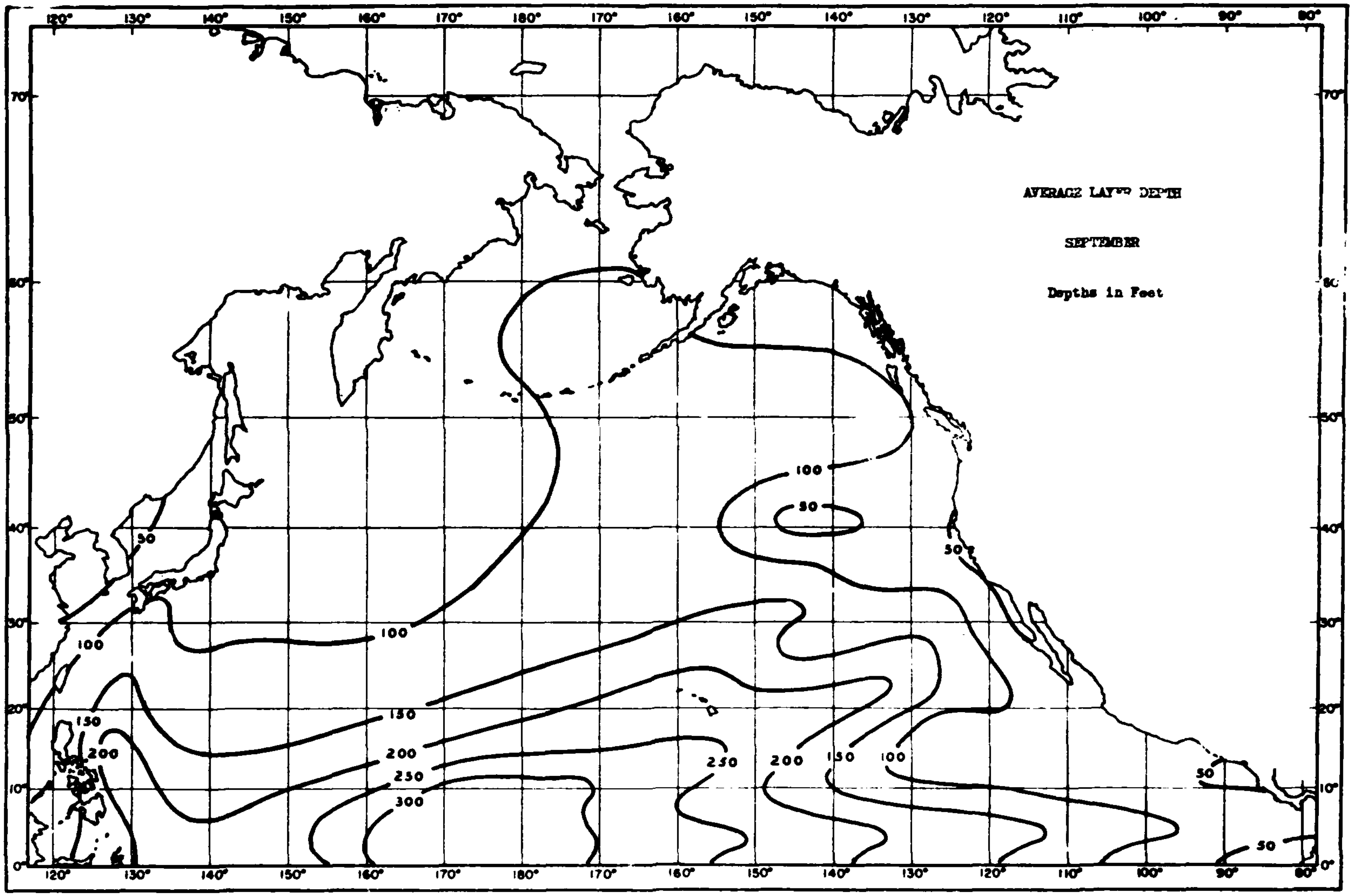


Figure 19.

ONR 416
6/21/60

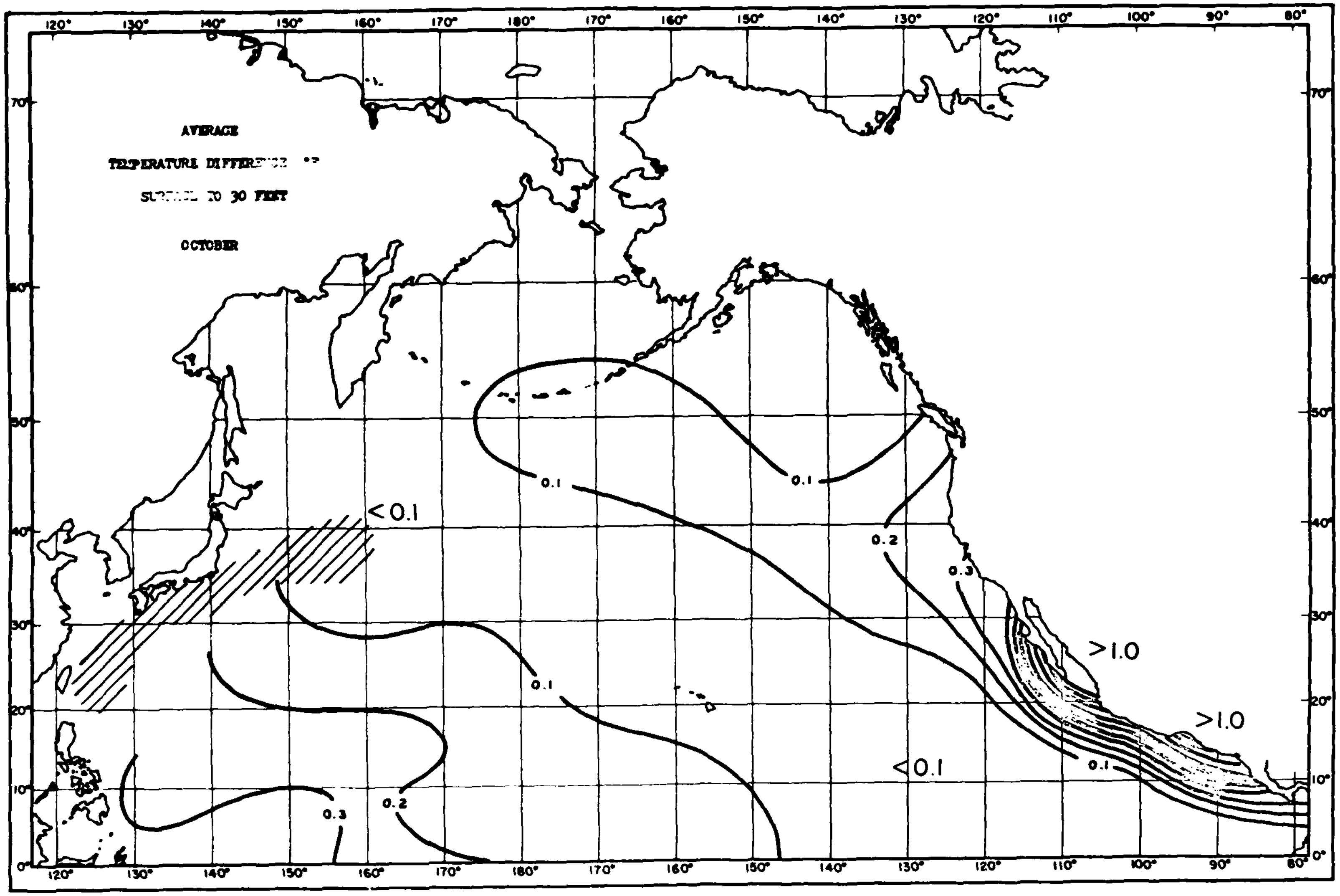
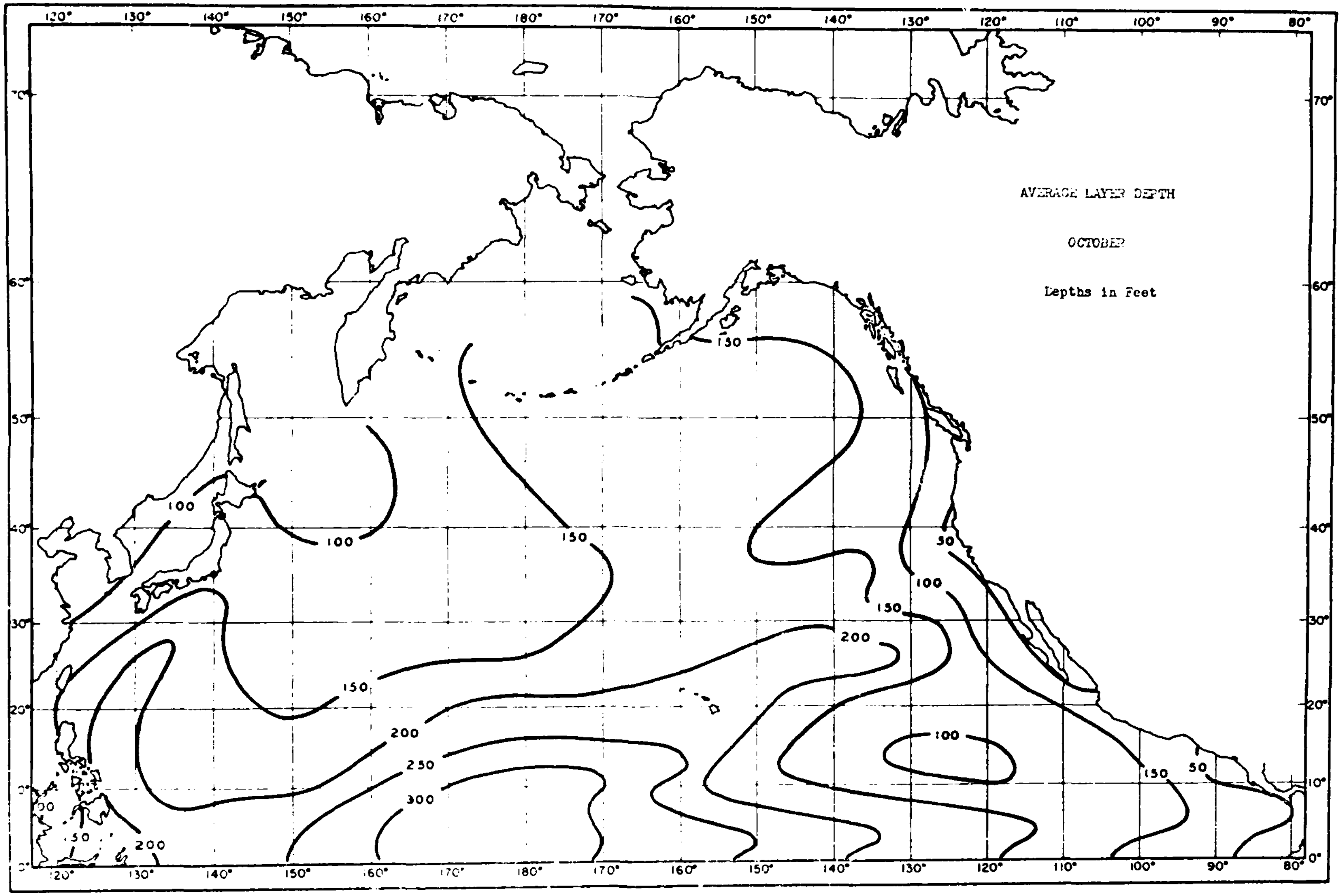


Figure 20.

ONR 416
6/21/60



AVERAGE LAYER DEPTH

OCTOBER

Depths in Feet

Figure 21.

ONR 416
6/21/60

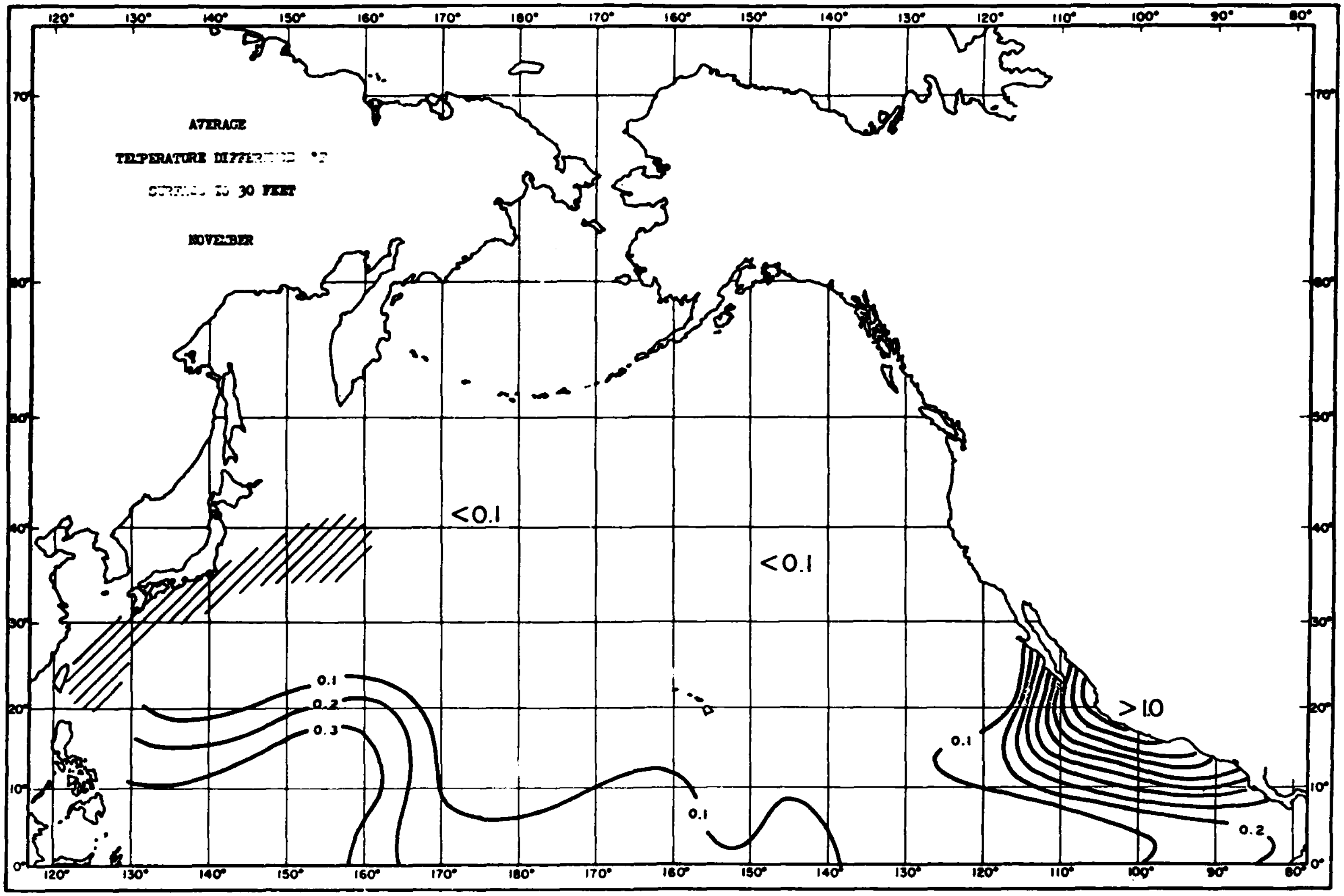
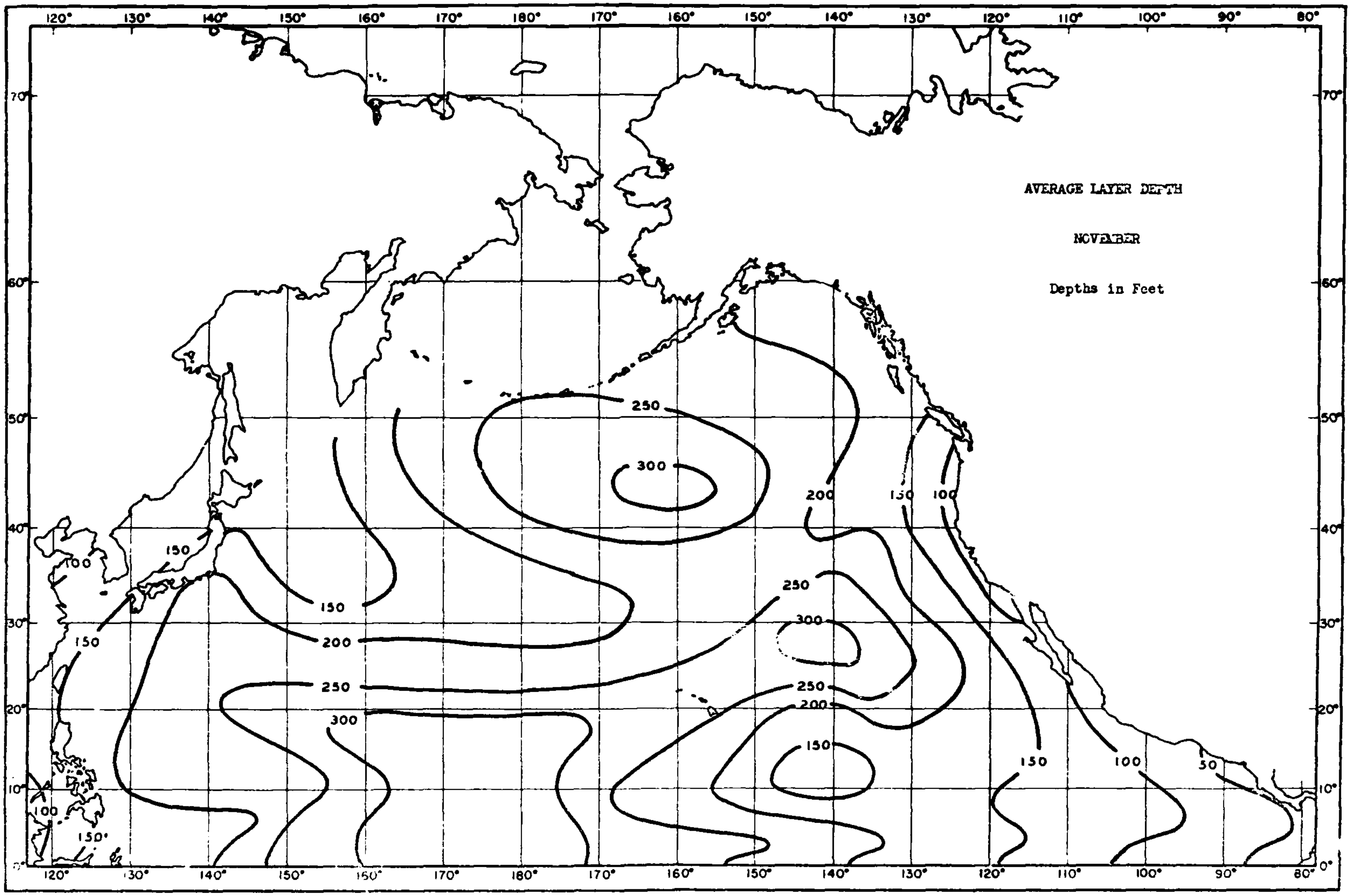


Figure 22.

~~CONFIDENTIAL~~
ONR 416
6/21/60


AVERAGE LAYER DEPTH

NOVEMBER

Depths in Feet

Figure 23.

~~[illegible]~~
ONR 416
6/21/60

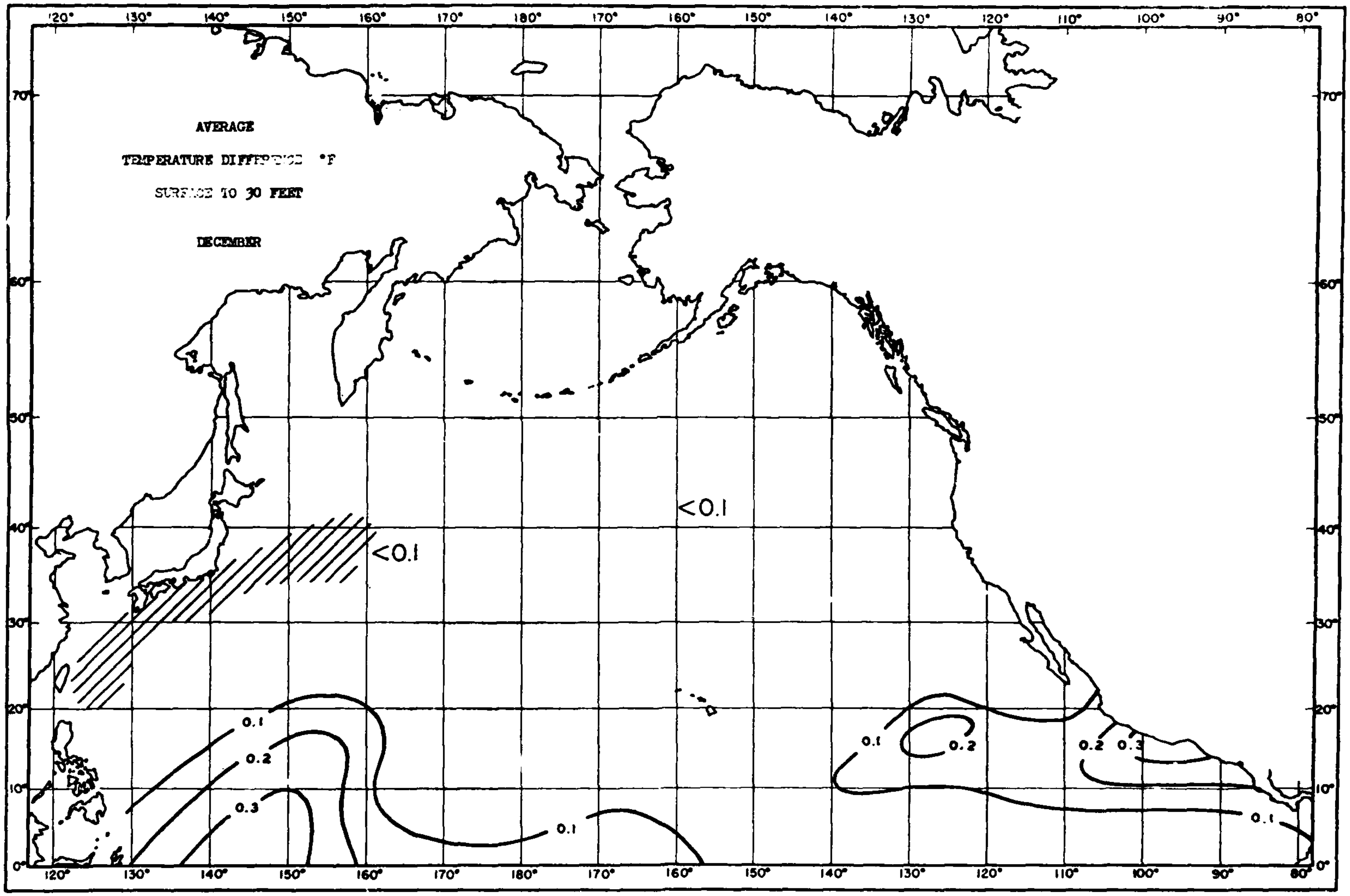
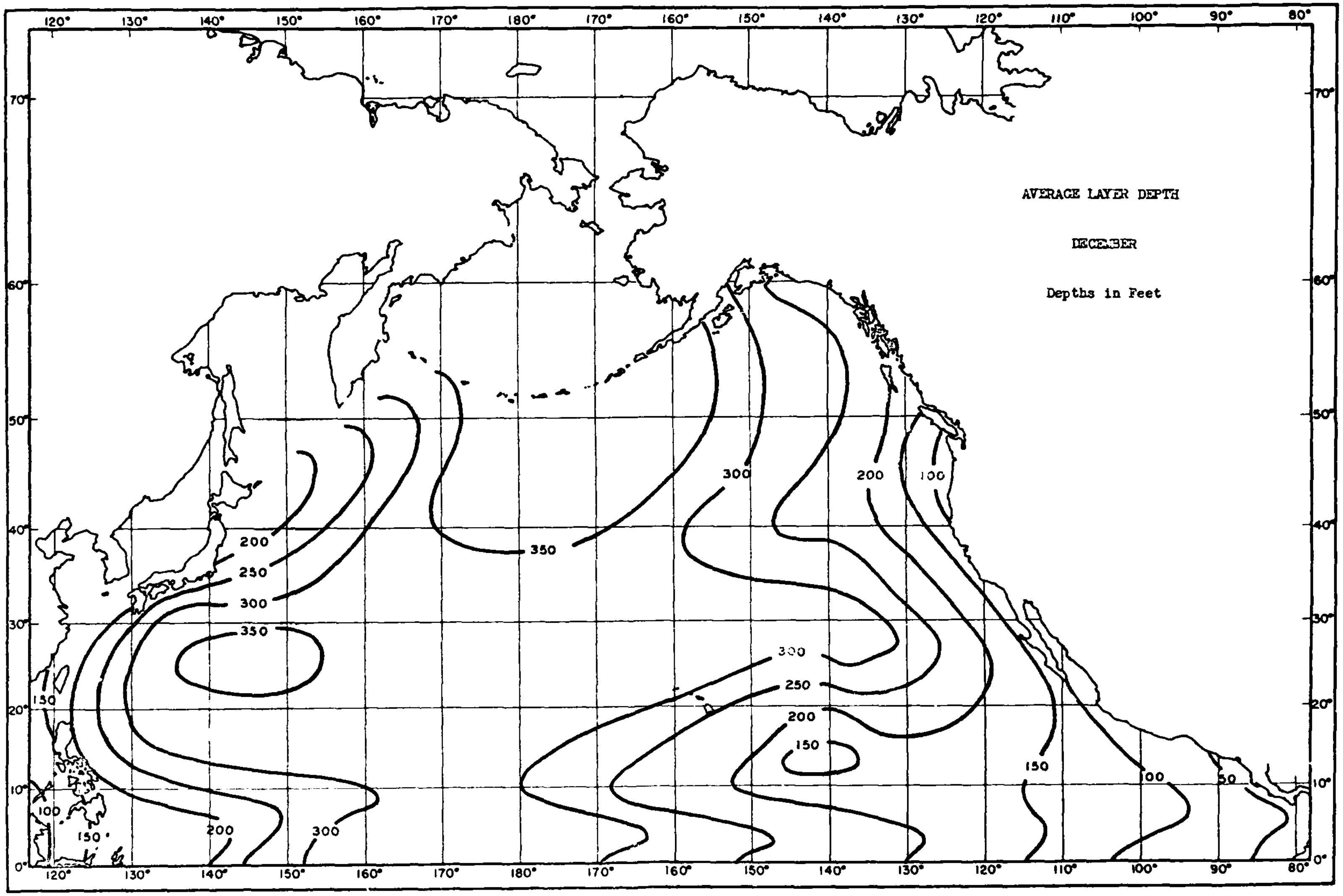


Figure 24.

~~CONFIDENTIAL~~
ONR 416
6/21/60



AVERAGE LAYER DEPTH

DECEMBER

Depths in Feet

Figure 25.

ONR 416
6/21/60